Northeast Fisheries Science Center Reference Document 20-05

Cetacean Abundance in the US Northwestern Atlantic Ocean Summer 2016

by Debra Palka

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ABSTRACT

From 27 June to 28 September 2016, as part of the AMAPPS (Atlantic Marine Assessment Program for Protected Species) project, the Northeast Fisheries Science Center (NEFSC) and Southeast Fisheries Science Center (SEFSC) of the National Oceanic and Atmospheric Administration Fisheries Service conducted nonoverlapping, line-transect, aerial and shipboard abundance surveys. In collaboration, Canadian scientists conducted similar aerial nonoverlapping line transect surveys over Canadian waters from the Bay of Fundy to eastern Labrador waters. The goal was to estimate abundance of as many cetaceans and sea turtles in the northwestern Atlantic Ocean as the data allowed. This document focuses on abundance estimates of cetaceans detected only during the NEFSC surveys that covered waters from North Carolina to Maine, from the shore to the Gulf Stream, which is about 370 km (200 nmi) offshore. In a study area of 425,192 km^2 the ship and plane surveyed 11,636 km of track lines. To estimate abundance, data collected with the two-independent-team method were analyzed by using mark-recapture distance sampling to account for perception bias and by using dive time patterns to account for availability bias. Overall, 325,242 cetaceans (CV = 0.19) of 23 species or species groups were estimated to be present in the NEFSC study area during the summer of 2016. It was estimated there were 39 (CV = 0.64) blue whales (*Balaenoptera musculus*); 52 (CV = 0.53) sei whales (*Balaenoptera borealis*); 55 (CV = 0.47) Blainsville's beaked whales (*Mesoplodon densirostris*); 703 (CV = 0.29) Sowerby's beaked whales (*Mesoplodon bidens*); 1153 (CV = 0.63) pygmy sperm whales (*Kogia breviceps*); 1182 (CV = 0.63) false killer whales (*Pseudorca crassidens*); 2368 (CV = 0.48) humpback whales (*Megaptera novaeangliae*); 2390 (CV = 0.38) fin whales (*Balaenoptera physalus*); 2562 (CV = 0.28) True's beaked whales (*Mesoplodon mirus*); 2802 (CV = 0.81) minke whales (*B. acutorostrata*); 3321 (CV = 0.35) sperm whales (*Physeter macrocephalus*); 3395 (CV = 0.62) dwarf sperm whales (*Kogia simus*); 5264 (CV = 0.37) Cuvier's beaked whales (*Ziphius cavirostris*); 5828 (CV = 0.30) Gervais' beaked whales (*Mesoplodon europaeus*); 8247 (CV = 0.24) Atlantic spotted dolphins (*Stenella attenuata*); 16,737 (CV = 0.37) pilot whales (*Globicephala spp.*); 16,995 (CV = 0.35) bottlenose dolphins (*Tursiops truncatus*); 21,897 (CV = 0.23) Risso's dolphins (*Grampus griseus*); 31,912 (CV = 0.61) Atlantic white-sided dolphins (*Lagenorhynchus acutus*); 42,873 (CV = 0.25) striped dolphins (*Stenella coeruleoalba*); 75,079 (CV = 0.38) harbor porpoises (*Phocoena phocoena*); and 80,227 (CV = 0.31) common dolphins (*Delphinus delphis*). The total abundance estimate for each species will be reported in the Atlantic Stock Assessment Report. For stocks that also reside south of the NEFSC survey area, the SEFSC abundance estimate will be added to the NEFSC's estimate. For stocks that also reside north of the NEFSC survey area, the Canadian abundance estimate will be added to the NEFSC's estimate.

INTRODUCTION

The US Marine Mammal Protection Act requires the status of marine mammal stocks in US waters to be evaluated on a regular basis. To meet this mandate, the NOAA Fisheries Service conducts research to define marine mammal stock structure and estimate the stock's abundance and human-caused mortalities. In response to the need for updated abundance estimates, the Northeast Fisheries Science Center (NEFSC) and Southeast Fisheries Science Center (SEFSC) of NOAA Fisheries Service collaborated with Fisheries and Oceans Canada in the summer of 2016 to conduct aerial and shipboard line-transect abundance surveys of marine mammals and sea turtles in the northwestern Atlantic from Labrador, Canada to Florida, United States. The resulting abundance estimates from these 3 surveys will be used to update species assessments that are reported in the US Marine Mammal Stock Assessments. The previous assessments for most species used abundance data collected during summer 2011 in waters from Halifax, Nova Scotia to Florida (Palka 2012; Waring et al. 2013; 2014; Garrison 2016).

The abundance data also support environmental assessments of ocean activities. Previous examples of marine mammal abundance data tailored to this usage include Roberts et al. (2016), Palka et al. (2017), and Chavez-Rosales et al. (2019). In addition, these data can be used to investigate the spatial-temporal trends in the distribution and abundance of these species which could be changing because of changes in the physical and biological characteristics of the US North Atlantic waters as discussed in Frederiksen and Haug (2015).

The US portion of this collaboration is part of the Atlantic Marine Assessment Program for Protected Species (AMAPPS) project, which is a multiagency, multiyear initiative to provide comprehensive assessments of marine mammal, sea turtle, and seabird abundance and spatial distributions in US waters of the western North Atlantic Ocean. The major funding partners of AMAPPS are NOAA Fisheries Service, Bureau of Ocean Energy Management, Environmental Studies program (BOEM), US Navy, and US Fish and Wildlife Service (USFWS).

This manuscript focuses on cetacean abundance estimates from the shipboard and aerial line-transect surveys conducted by the NEFSC from 27 June to 28 September 2016 in waters north of North Carolina. The abundance of cetaceans that reside north and south of the NEFSC survey area have been estimated by using data collected from the Canadian (Lawson and Gosselin 2018) and the SEFSC 2016 abundance surveys (Garrison 2020), respectively, which are reported elsewhere.

The present study used data collection procedures and analysis methods that were designed to account for 2 types of visibility bias that are related to visual line transect data collected from ships and planes (McLaren 1961). Availability bias is due to missing animals that were submerged and thus not available to be detected by visual observers on ships and planes. Perception bias is due to missing animals that were close enough to the surface to be detected but were missed for some other reason and were not recorded. This oversight could be due to a variety of reasons, such as distance from the observation platform, poor sighting conditions from sun glare or sea state, or cryptic animal behavior. To address perception bias, the shipboard and aerial surveys were designed to simultaneously collect line transect sightings data from 2 independent teams and were analyzed by using mark-recapture distance sampling (MRDS) methods. To address availability bias, animal dive patterns informed a correction factor that was then applied to the abundance estimates with the perception bias corrected.

MATERIAL AND METHODS

Study Area

The primary study area surveyed by the NEFSC covered 3 spatial strata (Figure 1; Table 1) that represent different spatial habitats:

- *Gulf of Maine (GOM)*: a stratum ranging in US waters from New York to Maine (about 39˚N – 45˚N latitude) and from the US shore to about the 100 m depth contour or the US Exclusive Economic Zone (EEZ). The NOAA Twin Otter airplane surveyed this stratum.
- *Shelf Break*: a stratum ranging from Virginia to the southern tip of Nova Scotia (about 38˚N – 42˚N latitude) and in waters between the 100 m and 2000 m depth contours. The NOAA ship *Henry B. Bigelow* surveyed this stratum.
- *Offshore*: a stratum ranging from North Carolina to waters south of the southern tip of Nova Scotia (about 36˚N – 42˚N latitude) and in waters offshore of the 2000 m depth contour to beyond the US exclusive economic zone and the Gulf Stream's northern wall. The NOAA ship *Henry B. Bigelow* also surveyed this stratum.

In addition, 2 small additional strata were surveyed and are part of a habitat-ecosystem study in prospective locations for wind energy projects (Table 1B):

- *BOEM-MA*: a stratum south of Massachusetts on the continental shelf in waters that are about 30 – 60 m deep (around 41˚N latitude).
- *BOEM-MidAtl*: 2 regions off the coasts of New Jersey and Delaware that are on the continental shelf in waters of about 20 – 30 m deep (between 38˚N – 40˚N latitude).

Both the NOAA Twin Otter plane and NOAA ship *Henry B. Bigelow* surveyed the 2 small additional strata. In this analysis, the shipboard data from the 2 small additional strata augmented the shipboard data within the primary strata only to improve the definition of the detection function. The abundance estimates from these wind energy areas will be reported in a separate document under the AMAPPS project.

Aerial Field Procedures

The 2016 NEFSC aerial abundance line transect survey covered the GOM stratum (including the BOEM-MA stratum) with a NOAA Twin Otter airplane during 14 August – 28 September 2016 (Figure 2). The survey was conducted along tracklines oriented either perpendicular to the coast or at an angle aligned to cut across the expected spatial onshore-offshore animal density gradients. The survey plane flew at an altitude of 183 m (600 ft) above the water surface, at a speed of approximately 200 kph (110 kts), and when surface wind speeds were less than about 20 kts (that is, approximately sea state 4 or less on the Beaufort scale).

"Extra" track lines were defined as either transit flights to the above-mentioned primary track lines or else track lines that overlapped with the summer 2016 shipboard shelf break stratum. In either case, the data collection methods on the extra track lines were identical to the normal on-effort procedures, thus allowing them to be used in an abundance analysis. In the habitat-density spatial models (Palka et al. 2017; Chavez-Rosales et al. 2019), the extra tracklines are included in the analysis. However, in this design-based analysis of only the 2016 summer data, data from the extra track lines were only used to estimate the parameters in the species detection functions.

The data entry program recorded Global Positioning System (GPS) locations automatically every 2 seconds, and it recorded environmental conditions, effort, and sighting information whenever entered by the observer teams.

On-effort time periods were when the plane flew level at survey altitude and speed on the track line. During these periods observers concentrated their visual search for animals within the region bound by straight down to the track line (0˚ inclination angle) to approximately 300 m from the track line (about 60˚ above vertical) and from as far forward as possible to slightly behind the plane, although time was also spent searching farther from the track line. When an observer detected a group of animals, the observer waited until the group was perpendicular to the plane, and then measured the angle (to the nearest degree) from vertically straight down to the center of the group by using a digital inclinometer or markings on the windows.

The 2 simultaneous-team procedure involved 6 scientists onboard the plane that operated as 2 independent teams. The front team consisted of 3 scientists: 2 observers looking through forward bubble windows on either side of the plane and a dedicated data recorder collecting data from only the front team. The bubble windows allowed downward visibility including the trackline and unobstructed views to the horizon. The back team consisted of 3 scientists: one observer looking straight down through a belly window, another observer looking through a rear bubble window on the right side of the plane, and a dedicated data recorder collecting data from only the back team. The belly window observer had visibility of approximately 110 m (30˚) on either side of the trackline. The back bubble window observer had the same viewing area as the front right bubble window observer. The 2 observation teams operated on independent intercom channels and were not able to alert each other. Observers rotated between the 4 sighting positions about every 30 minutes, while recorders stayed at the same positions the entire flight.

Data collected included information on sightings, effort, and environmental characteristics. For each cetacean group detected, the observers recorded the following data:

- time of detection when sighting was perpendicular to the observer;
- observer who detected the group;
- plane's latitude and longitude;
- angle of declination to the center of the group;
- species identification;
- level of certainty of the species identification (certain, probable, not sure);
- group size;
- compass direction the group was swimming towards;
- initial cue that caught the observers eye (animal, splash, blow, footprint, birds, vessel or gear, windrows, disturbance, bubbles, or other);
- initial behavior (swimming, milling, breaching, charging, feeding, logging, diving or other), and
- comments.

Effort and environmental data collected included:

- time and location when starting or ending a track line or when another effort variable was updated;
- observers' positions;
- Beaufort sea state condition (0 – 6 in one decimal increments);
- percent cloud cover (0-100%);
- location of the glare swath;

- severity of the glare within that swath (none, slight, moderate, or severe);
- overall quality of sighting conditions for each observer (excellent, good, moderate, fair, or poor); and
- comments.

Duplicate sightings (groups seen by both teams) were based upon time, location, and position relative to the trackline and were determined either in the plane or after the survey.

At times the observers requested the plane to circle a group to verify species identification and group sizes. The circling time was considered off-effort and not included in the abundance estimate. If the front team made the initial sighting within about 300 m (60°) of the track line and they were unable to identify the species, they waited until the sighting was aft of the plane to allow the back team an opportunity to detect the sighting, then they asked the pilots to break effort and circle the sighting. Additional animal groups detected during off-effort periods were classified as off-effort and not used in this analysis.

Shipboard Field Procedures

The 2016 NEFSC shipboard abundance line transect survey covered the shelf break, offshore, BOEM-MA and BOEM-MidAtl strata with the NOAA ship *Henry B. Bigelow* from 27 Jun to 25 Aug 2016 (Figure 2). A few parts of the track line surveyed in Beaufort 4 or 5 conditions were resurveyed in better sighting conditions at a different time within the survey time window. In these cases, only the effort and sightings from the times that were surveyed in the lowest Beaufort state were included in the analysis.

Two teams simultaneously collected visual line transect data. Each team consisted of 3 on-duty observers and 1 observer at rest. The upper team was located on the flying bridge, 15.1 m above the sea surface, and the lower team was on the roll tank platform that was in front of the bridge and was 11.8 m above the sea surface. Within each team, 2 observers searched with 25x150 powered binoculars, and 1 observer recorded the team's data while searching with the naked eye, concentrating on waters close to the ship that could be overlooked by the observers searching with high-powered binoculars. Observers changed positions within their team every 30 minutes. During daylight hours, when weather permitted (i.e., at least 3.7 km visibility and Beaufort <5), observers searched the waters in front of the ship within a region bound by 90° on both sides of the transect line, and from the ship to the horizon.

Data collected included information on sightings, effort, and environmental characteristics. For each cetacean group detected, sightings data included:

- time of initial detection;
- ship's latitude and longitude;
- bearing between the transect line and line of sight to the location of the group;
- radial distance between the ship and center of the group;
- species composition;
- level of certainty of the species identification (certain, probable, not sure);
- group size;
- initial behavior of the group (swimming, porpoising, charging, aerobatics, bow riding, breaching, diving, feeding, fluking, logging, milling, motionless, unknown, or other);
- initial sighting cue that attracted the observer to the group (body, splash, blow, footprint, birds, vessel or gear, windrow, or other); and

- comments.

Bearings were measured by using angle rings around the tripod-mounted binoculars or angle boards mounted on the recorder's desk. Radial distances were measured with reticles in the eyepiece of the binoculars. The group size was considered to be the team's best estimate, where the size of the group was assessed as often as possible as the group passed by the ship.

Effort and environmental data included:

- time of the data entry event;
- observers' positions;
- swell height and direction;
- Beaufort sea state condition (0 – 6 in 1 decimal increments);
- magnitude of the sun glare (none, slight, moderate, severe);
- cloud coverage;
- presence of rain or fog; and
- approximate visibility distance.

The ship's instruments collected other environmental characteristics and recorded the following every second:

- ship's location;
- ship's speed and course;
- true wind speed and direction;
- water depth;
- water surface temperature;
- air temperature; and
- water current direction and speed.

When it was not possible to confirm the species identification or group size and the group was within a couple miles from the ship, the ship went off-effort and approached the group to a distance where it was possible to confirm the identification and/or group size. The observers initiated the approach procedure only after it was nearly 90° abeam or after both teams detected the group. Since both teams were off-effort when approaching a group, any additional sightings were labeled as off-effort.

Aerial and Shipboard Field Procedures

For both the shipboard and aerial surveys, in addition to recording marine mammals and sea turtles, observers also recorded groups of fish species, especially large sharks because they could be confused with a marine mammals. Not all fish sightings were recorded, particularly if it was thought to be interfering with searching for marine mammals. Observers identified species to the lowest taxonomic level possible. When they could not distinguish the animals to the species level, a species groupings was used. For example, the species could be identified as "pilot whale spp." because it was not possible to distinguish confidently between short-finned (*Globicephala macrorhynchus*) and long-finned (*G. melas*) pilot whales. Species groupings such as "unidentified dolphin" were used when it was only possible to determine the animals were dolphins of some species. The abundance analyses did not use data from most groups identified to a level with the word "unidentified." Using the data from these groupings could result in negatively biased abundance estimates because an unknown proportion of the unidentified groups may have included individuals of any given species. Many of the unidentified groups were far from the track line and thus beyond the analysis truncation distance.

Analytical methods

In summary, analyses of both shipboard and aerial data resulted in abundance estimates accounting for perception bias using mark-recapture distance sampling (MRDS; Buckland et al. 2004), which was then multiplied by a dive time correction factor to account for perception bias.

Because it is harder to detect animals from a plane than from a ship, especially smaller animals, aerial data collected under Beaufort sea states of 4 or less were used to estimate abundance for all species except harbor porpoises, which used data collected under Beaufort sea states of 2 or less. In contrast, shipboard data collected under Beaufort sea states of 5 and less were used to estimate the shipboard abundance estimates, though only 3% of the shipboard track lines were surveyed in Beaufort 5 conditions.

Abundance estimates accounting for perception bias were based on the independent observer approach assuming point independence (Laake and Borchers 2004) and calculated by using the mark-recapture distance sampling (MRDS) functions (Laake et al. 2018) within R (version 3.5.1, R Core Team 2017). This analysis method based on the abundance of groups and expected size of the groups is an extension of standard line-transect distance analysis. In MRDS the sighting probability on the trackline implicitly includes the estimation of *g(0)*, which is the probability of detection of a group on the trackline. The probability of sighting a particular group is the product of 2 components. The first probability component is the distance sampling (DS) component that corresponds to the standard unconditional detection function. This component is defined as the probability of one or more observer teams detecting the group of animals, given its distance and possibly covariate values. The probability of detection declines with increasing distance from the trackline following a known functional form (the half-normal or hazard function were used in this analysis). The second probability component is the mark-recapture (MR) component that is a conditional detection function. This component is defined as the probability of one team detecting the animal group, given the other team has detected it and given its' distance and perhaps covariate values. The MR component results in a probability likelihood of detection on the trackline, which is modeled by using a logistic regression approach and the "capture histories" of each sighting (i.e., seen by one or both teams). Laake and Borchers (2004) detailed the derivation, assumptions, and implementation of this estimation approach.

Because of the physical limitations within the plane, the front and back teams could not search the exact same patch of water. The front team had full viewing coverage: from the horizon on the right side of the plane (90°), down to directly under the plane (on the track line; 0°), then over to the horizon on the left side of the plane (90°). The back team had limited viewing coverage: from the horizon on the right side of the plane, down under the plane through the track line, then over to about 30 – 35° from the track line on the left side of the plane. To account for this asymmetry, a two-step procedure estimated the perception-bias corrected density for the aerial data. The first step was to estimate the average probability of the primary team detecting a group at the track line, given the perpendicular distances and covariates (*p(0)*) in a two-team MRDS analysis using only data collected from the area both teams could see. The second step used data only from the primary team in a standard single team multiple covariate distance sampling (MCDS) analysis to estimate densities that were then expanded by the average estimate of *p(0)* for the primary team (as estimated in the first step). The primary team was the team that collected data resulting in the typically shaped detection function declining monotonically from the trackline.

Perpendicular distances were right truncated following guidance in Buckland et al. (2001), thus accounting for differences in species and observers, observers' searching behavior and surveying conditions, etc. The tests used to determine the best-fitting models with the appropriate significant covariates included the Akaike Information Criterion (AIC), the Cramér-von Mises test, quantile-quantile plot fits, and visual inspection of the fitted models (Marques and Buckland 2003). Possible model forms of the DS models were the half-normal and hazard key functions. For the MR model, interactions between covariates were also investigated, particularly interactions with the team, thus allowing the shape of the fitted curve to differ by team. To account for possible multi-collinearity between covariates in the detection function, following the conclusions of Dormann et al. (2013), only one covariate of pairs of covariates that had a correlation coefficient of $|r|>0.7$ were used in the model. However, Dormann et al. (2013) also pointed out that collinearity is a severe problem when a model is trained on data from one region or time and predicted to another with a different or unknown structure of collinearity. This situation is not applicable in this analysis.

At times, data from similar species were pooled in the analysis to ensure sufficient sample size to estimate the model parameters. For example, a global MRDS analysis used data from all beaked whale (Ziphiidae) sightings. Then, individual covariate values from each species applied to the global function resulted in species-specific detection functions. Finally, a species-specific abundance was estimated by using the detection functions, expected group sizes, and encounter rates.

In some cases, observers were only able to identify the animals as 1 of 2 (or more) species. For example, some groups had animals that were considered to be either a fin whale (*Balaenoptera physalus*) or sei whale (*Balaenoptera borealis*), or considered as some sort of Mesoplodont beaked whale, or as one of the *Kogia* whales. The positively identified and ambiguous sightings were part of the estimation process. For example, the final abundance of fin whales was calculated by defining the final abundance estimate of fin whales ($abun_{all.fin}$) to be the sum of the abundance of positively defined fin whales ($abun_{pos.fin}$) and a portion of the abundance estimate of animals identified as either a fin or sei whales ($abun_{fin/sei} * g$):

$$abun_{all.fin} = abun_{pos.fin} + \left(abun_{fin/sei} * g\right) \qquad Eq.1$$

where

$$g = \frac{abun_{pos.fin}}{abun_{joint}}$$

$$abun_{joint} = abun_{pos.fin} + abun_{pos.sei}$$

and

$$var\left(abun_{fin/sei} * g\right) = \left(\frac{g*(1-g)}{abun_{joint}-1}\right).$$

The estimates of the abundance of individual species within the groups of unidentified *Mesoplodont* beaked whales, unidentified Ziphiidae, *Kogia* spp and common/white-sided dolphins resulted from this same proration procedure.

The coefficient of variation (CV) of the abundance estimates was estimated by using the delta method and empirical variance in encounter rate between samples (Buckland et al. 2001; Fewster et al. 2009). The CV of the abundance estimates that included a portion of ambiguous groups included the variance of this portion.

The abundance estimate accounting for both perception and availability bias was calculated by:

$$abundance_{perception-bias\ corrected} * availability\ correction\ factor \quad \text{eq. 2}$$

where the perception-bias corrected abundance estimate is that described above by using mark-recapture distance sampling methods, and the availability bias correction factor is derived from Palka et al. (2017). The current paper used the inverse of the correction factors presented in Palka et al. (2017) simply because the interpretation of a correction factor is easier to understand when the factor is multiplied to the perception-bias correction abundance estimate (this paper) in contrast to dividing the perception-bias correction abundance estimate by a correction factor, as presented in Palka et al. (2017). The correction factor, developed by Laake et al. (1997; equation 7), was defined as the probability that an animal group at a perpendicular distance (x) was at the surface and within the observer's field of view. It was modeled as a 2-state continuous-time Markov process, requiring the average time at the surface (representing time available to be seen), average time at depth (representing time unavailable to be seen), and amount of time a group at perpendicular distance x from the trackline remained in view of the observers. Since the average surface and dive times were estimated from individual animals and the correction factor needs to represent a correction for groups (which was the unit used in the abundance estimate accounting for perception bias), the group sizes as observed during the surveys were also accounted for. A full description of this calculation is in Palka et al. (2017).

RESULTS

General

The ship surveyed the shelf break, offshore, BOEM-MA, and BOEM-MidAtl strata (Figure 2) during 3 legs. Leg 1 was 27 Jun – 14 Jul 2016 (18 days), leg 2 was 18 Jul – 5 Aug 2016 (19 days), and leg 3: 9 Aug – 25 2016 (17 days), where 239.9 hours of on-effort surveying was realized during 37 good weather survey days out of the total 54 days available. An additional 47.6 hours were spent surveying tracklines in less ideal conditions (Beaufort 4 or more) which were then resurveyed in better conditions, and so the data from only the better conditions were used in the analysis.

The plane surveyed the GOM stratum from 14 Aug to 28 Sept 2016, where 40.6 hours of on-effort surveying was realized during 16 good weather flight days (Figure 2). An additional 20.4 hours were spent surveying the "extra" track lines that were used in the estimation of the detection function but not the encounter rate (as explained in the methods section).

Within the primary strata, both platforms surveyed 11,636 km of track lines within a study area of 425,192 km^2 (Table 1). About 88% of the track lines were surveyed in Beaufort sea states of 3 or less (Table 1A; Figure 2). About 3,880 and 618 km of effort was surveyed on the "extra" aerial and shipboard track lines, respectively (Table 1B). Because this is design-based analysis, the level of coverage within the shelf break stratum varied substantially, and the portion with the higher intensity of searching effort happened to coincide with higher animal density, it was necessary to poststratify the shelf break stratum into 2 substrata (Shelf-hi and Shelf-lo) to ensure the overall density in the shelf break stratum was unbiased (Table 1C; Figures 1-2).

The shipboard survey detected 22 cetacean, 2 turtle, and 1 seal species, along with several fish species – in particular basking sharks (*Cetorhinus maximus*) and ocean sunfish (*Mola mola*) (Table 2). The aerial survey detected 11 cetacean, 4 turtle, and 1 seal species, along with several fish species (Table 2). The locations of the cetacean sightings detected by the 2 platforms are in Figures 3-19. A general description of the distribution of the species is as follows:

- Species located either completely or nearly all within the Gulf of Maine stratum included Atlantic white-sided dolphins (*Lagenorhynchus acutus)*, harbor porpoises (*Phocoena phocoena)*, and minke whales (*Balaenoptera acutorostrata)*;
- Species found in the Gulf of Maine and on the shelf break included fin whales, humpback whales (*Megaptera novaeangliae*), sei whales, and common dolphins (*Delphinus delphis*);
- Species found on the shelf break and in deeper waters included Atlantic spotted dolphins (*Stenella attenuata)*, beaked whales, sperm whales (*Physeter macrocephalus*), and striped dolphins (*Stenella coeruleoalba)*;
- Species found mostly in waters deeper than the shelf break included dwarf sperm whales (*Kogia simus*), false killer whales (*Pseudorca crassidens*), pygmy sperm whales (*Kogia breviceps*), and spinner dolphins (*Stenella longirostris*);
- Species found throughout the study area included bottlenose dolphins (*Tursiops truncatus*), Risso's dolphins (*Grampus griseus)*, and pilot whales (*Globicephala spp.*).

Abundance Estimates

Potential covariates for the abundance models (Table 3) include variables describing the sighting conditions (Beaufort sea state, cloud cover, glare, sighting time, swell height, turbidity, visibility distance, and a subjective evaluation of the overall quality of sighting conditions) and animal group characteristics (behavior, cue, group size, species identification, and swim direction). Diagnostic plots from the MRDS and MCDS distance sampling analyses for the species groupings from the aerial and shipboard surveys are in Appendices A and B, respectively. The diagnostics include scaled histograms of each team's detections, conditional mark-recapture detection functions for each team given detections from the other team, and quantile-quintile plots showing goodness of fits.

The average group sizes of large whales and *Kogia* spp. were the smallest: fewer than 2 animals per group per species (Table 4). Harbor porpoises and beaked whales had slightly larger average group sizes: fewer than 4 animals per group per species. Average group sizes of Risso's dolphins, bottlenose dolphins, and pilot whales were fewer than 10 animals per group per species. Average group sizes of the other dolphin species (common dolphins, Atlantic white-sided dolphins, Atlantic spotted dolphins, and striped dolphins) were the largest: on average 11 – 60 animals per group per species. Of the species that inhabited all parts of the study area (common dolphins, Risso's dolphins, and pilot whales), the average group sizes were smaller for the groups detected in the Gulf of Maine than for those of the same species that were detected farther offshore on the shelf break and in deeper water.

The covariates that most commonly contributed significantly to the DS detection function models were group size and some descriptor of the sighting condition (as quantified by sightTime, glare, or beaufort), while group size was the most common covariate in the mark-recapture MR models (Table 5). For the MR models from the aerial data, observer team was commonly significant, while for the shipboard data, glare was commonly significant. The estimated effective strip width of the primary team ranged from about 100 – 200 m for harbor porpoises and dolphins detected from the plane to about 2000 m or more for humpback and sperm whales detected from the ship (Table 5). The shortest effective strip width from the shipboard data was 1,071 m (CV = 0.23) for beaked whales.

Availability bias correction factors included in the analysis were the inverse of those developed in Palka et al. (2017) and are presented in Table 6.

Intermediate abundance estimates used as input into equation 1 to derive the abundances of species that include some groups with ambiguous identification are in Table 7. For example, in the shelf stratum an estimate of 141 animals (CV = 0.53) detected by the ship were ambiguously identified as either fin or sei whales (Table 7). Using equation 1 and the data in Table 6, the estimated 141 animals were prorated and added to the abundance estimates of positively identified fin whales (1,443 CV = 0.43) and positively identified sei whales (25 CV = 0.61; Table 7) to result in the final abundance estimates (Table 8) of 1,581 (CV = 0.39) fin whales and 28 (CV = 0.55) sei whales. The same process prorated the abundance of the following: unidentified Mesoplodonts to 4 beaked whale species (not including Cuvier's beaked whale); unidentified Ziphiidae to all 5 beaked whale species; *Kogia* spp. to dwarf sperm and pygmy sperm whales; and common/white-sided dolphins to common and white-sided dolphins. Abundance estimates from ambiguous sightings labeled as Delphinus/Stenella, Risso's/Bottlenose dolphins, Stenella spp., unidentified dolphin, or unidentified whale were not added into any abundance estimates of positively identified species because it was not clear if the strategy used in equation 1 was the appropriate approach for such general groupings.

Total abundance of the 23 species observed in the surveyed area was 325,242 animals (CV = 0.19; Table 8). Abundance estimates range from less than 100 animals per species rarely seen in US waters during the summer (for example, blue and sei whales), to over 40,000 animals per species of harbor porpoises, striped dolphins and common dolphins.

DISCUSSION

The goal of this effort was to incorporate visibility biases in the estimate abundance of cetaceans. To accomplish this goal, visual 2-team line transect data collected from shipboard and aerial observation platforms were used in mark-recapture distance sampling analysis methods to estimate abundance while incorporating perception bias. This estimate was then multiplied by a species-specific availability bias correction factor that was derived from species-specific dive patterns. In total, abundance estimates for 23 species (or species groups) were calculated. These numbers represent the most recent estimates available that could be used in stock assessments.

The current abundance estimates in this document are not directly comparable to those reported previously in the Stock Assessment Reports (Waring et al. 2013). The current analysis is similar to previous analyses (Palka 2012) in that they both used mark-recapture distance sampling techniques and included significant covariates that affected the detection functions to account for perception bias caused by missing available animal groups. The current analysis differs from previous analyses in 2 major ways. One difference is that this survey was conducted mostly in US waters (because Canadian scientists surveyed Canadian waters). The effect of this difference is that the current NEFSC 2016 estimates are expected to be smaller than previous NEFSC estimates, such as from 2011 (Palka 2012). This difference is particularly true for species that utilize the northern habitats, like harbor porpoises. The Gulf of Maine stratum surveyed by airplane was 13.5% smaller in 2016 than that from 2011 (199,656 km^2 in 2011 versus 172,746 km^2 in 2016). In contrast, the shelf break and offshore strata surveyed by ship in 2011 and 2016 are essentially the same: 252,032 km^2 in 2011 versus 252,446 km^2 in 2016, a 0.2% difference. The second difference is only the current analysis accounts for availability bias caused by missing unavailable animals. The effect of this difference is the current estimates are expected to be larger than previous estimates for the same study area. The effect of this is largest for deep diving species detected on the shipboard survey (sperm and beaked whales) and all species detected on the aerial survey. The magnitude of the difference is the magnitude of the correction factors (Table 6). Of course, there is natural interannual variability in the number of animals that were truly in the study area that confounds the easy comparison between current and previous estimates.

Process error was not explicitly accounted for in this analysis. Process error can be due to interannual variability in the number of animals truly present within the study area. This variability could be due to random animal movement patterns both within the study area or between inside and outside of the study area. The variability could also be due to an individual animal moving in response to changing physical and biological ocean conditions. Because of interannual variability, it is feasible that environmental factors incorporated in spatially explicit habitat-density models may help explain the variability in the encounter rates and group sizes and thus produce more precise abundance estimates. Examples of environmental factors include water temperature, bottom depth, presence/intensity of temperature or salinity fronts, and magnitude of chlorophyll and fish biomass. Palka et al. (2017) and Chavez et al. (2019) reported seasonal abundance estimates averaged over 2010 – 2013 that were developed from spatially and temporally explicit habitat density models that incorporated environmental factors. Roberts et al. (2016) developed habitat spatial models that resulted in monthly/seasonal averages over 1992 – 2014. The spatially explicit habitat-density models used in Chavez et al. (2019) are currently being updated to use the 2010 – 2017 shipboard and aerial surveys from the NEFSC and SEFSC surveys. When completed we plan to compare the habitat-based estimates with the design-based estimates presented here.

In conclusion, the abundance estimates presented here have been included in the Atlantic Stock Assessment Reports to update the status of 23 US Atlantic cetacean stocks (Hayes et al. 2020). These estimates are an improvement over previously reported estimates because of the large areal coverage of the species' habitat by the surveys conducted by the SEFSC, NEFSC, and Canada DFO and the incorporation of the correction factor for availability bias.

Future work plans include utilizing the previous and current estimates in trends analyses using the summer abundance estimates from a longer time period, from 1992 to 2016. To make comparisons between years as comparable as possible, the strategy will be to standardize the abundance estimates to the same spatial region and include all appropriate corrections (such as for g(0), perception bias, and availability bias). However, even after standardizing the estimates as much as is possible, process error will most likely exist because of interannual variability in the number of animals present within the study area. Consequently, the plan is for the trend analysis to include environmental factors with the hope to explicitly estimating the process error.

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Table 1.General description of each stratum covered by the Northeast Fisheries Science Center's aerial and shipboard surveys. Description includes the area (in km2), platform used, and length of track lines (in km) covered during Beaufort sea state levels. A. Description of primary strata. B. Description of the Gulf of Maine (GOM) extra tracks (used to augment the estimation of the aerial detection function) and the 2 BOEM (Bureau of Ocean Energy Management) strata (used to augment the estimation of the shipboard detection function). C. Description of the substratification of the shipboard shelf break stratum.

			Track line length (km) within Beaufort sea state levels						
Strata	Area (km^2)	Platform	0	1	2	3	4	5	Total
A. Primary strata									
Shelf break	54,493	ship	0	235	631	690	351	97	2,003
Offshore	197,953	ship	20	159	468	616	447	21	1,731
GOM	172,746	plane	998	2,710	2,007	1,748	429	12	7,903
TOTAL	425,192	ship + plane	1,018	3,104	3,106	3,053	1,226	130	11,636
Proportion of total			0.09	0.27	0.27	0.26	0.11	0.01	1.00
Cumulative proportion of total			0.09	0.35	0.62	0.88	0.99	1.00	
B. Extra track lines									
GOM-extra tracks	3,852	plane	469	1,458	936	890	101	27	3,880
BOEM-MA	2,563	ship	0	0	105	26	34	29	195
BOEM-NJ	8,672	ship	0	0	159	143	121	0	423
C. Shelf break substrata									
Shelf-hi	32,954	ship	0	149	523	456	159	77	1,363
Shelf-lo	21,539	ship	0	86	108	234	192	20	640

Table 2A. Number of detected cetacean groups by species (or species group), team, and platform.

Species Common Name	Species Latin Name	Ship Low	Ship Up	Plane Back	Plane Front	Extra Plane Back	Extra Plane Front
Atlantic spotted dolphin	*Stenella attenuata*	15	12	0	0	0	0
Atlantic white-sided dolphin	*Lagenorhynchus acutus*	2	2	6	10	4	8
Blainsville's beaked whale	*Mesoplodon densirostris*	0	1	0	0	0	0
Blue whale	*Balaenoptera musculus*	3	3	0	0	0	0
Bottlenose dolphin	*Tursiops truncatus*	87	95	7	10	9	15
Common dolphin	*Delphinus delphis*	98	111	22	46	18	23
Common/white-sided dolphin	-	0	0	7	11	1	5
Cuvier's beaked whale	*Ziphius cavirostris*	23	21	0	0	0	0
Delphinus/Stenella	-	17	22	0	0	0	0
Dwarf sperm whale	*Kogia simus*	8	7	0	0	0	0
False killer whale	*Pseudorca crassidens*	4	3	0	0	0	0
Fin whale	*Balaenoptera physalus*	118	117	1	5	3	6
Fin/sei whales	*B. physalus or B. borealis*	6	19	0	1	1	2
Gervais' beaked whale	*Mesoplodon europaeus*	7	4	0	0	0	0
Harbor porpoise	*Phocoena phocoena*	0	0	70	69	5	9
Humpback whale	*Megaptera novaeangliae*	48	54	8	25	0	1
Minke whale	*B. acutorostrata*	0	2	3	14	3	4
Pilot whales spp	*Globicephala spp.*	80	82	4	7	12	17
Pygmy sperm whale	*Kogia breviceps*	2	6	0	0	0	0
Pygmy/dwarf sperm whales	*Kogia spp.*	16	15	0	0	0	0
Risso's dolphin	*Grampus griseus*	146	152	4	8	6	8
Risso's/Bottlenose dolphins	-	2	9	0	0	0	0
Sei whale	*Balaenoptera borealis*	2	4	0	0	0	0
Sowerby's beaked whale	*Mesoplodon bidens*	4	2	0	0	0	0
Sperm whale	*Physeter macrocephalus*	91	83	0	0	0	1
Spinner dolphin	*Stenella longirostris*	1	1	0	0	0	0
Stenella spp.	*Stenella spp.*	22	23	0	0	0	0
Striped dolphin	*Stenella coeruleoalba*	61	58	0	1	0	0
True's beaked whale	*Mesoplodon mirus*	3	5	0	0	0	0
Unidentified dolphin	*Delphinidae*	134	119	5	21	6	15
Unidentified whale	*Mysticeti*	51	52	5	7	0	4
Unidentified Mesoplodon	*Mesoplodon spp.*	27	27	0	0	0	0
Unidentified Ziphiidae	Ziphiidae	30	26	0	0	1	0
TOTAL CETACEANS		1108	1137	142	235	69	118

Table 2B. Number of other species detected, by species (or species group), team, and platform.

Species Common Name	Species Latin Name	Ship Low	Ship Up	Plane Back	Plane Front	Extra Plane Back	Extra Plane Front
Basking shark	*Cetorhinus maximus*	16	23	46	71	20	25
Hammerhead shark	*Sphyrna spp.*	0	0	32	33	0	0
Ocean sunfish	*Mola mola*	23	18	94	131	94	124
Green sea turtle	*Chelonia mydas*	0	0	3	4	1	1
Leatherback sea turtle	*Dermochelys coriacea*	5	6	6	12	1	1
Loggerhead sea turtle	*Caretta caretta*	17	15	157	232	58	94
Kemp's ridley sea turtle	*Lepidochelys kempii*	0	0	0	0	1	2
Unidentified turtle	*Chelonioidea*	4	1	20	43	14	12
Unidentified seal	Pinniped	0	1	51	46	17	16
TOTAL ALL SPECIES		1,173	1,201	551	807	275	393

Table 3. Description of covariates used in abundance analyses of the aerial and shipboard data.

Abbreviation	Description	Platform	Type	Values
beaufort	Beaufort sea state	Both	continuous	0-6, in increments of 0.1
behav	Initial activity of the group	Both	factor	Low profile (swimming, feeding, logging, milling, motionless); Medium profile (diving, bow riding, fluking, porpoising); High profile (aerobatics, charging, breaching)
cloudCov	Percent cloud cover	Both	continuous	0-100, usually in increments of 5
cue	Feature of sighting that initially was detected	Both	factor	Low profile (body; footprint); Medium profile (splash, birds, disturbance, bubbles); Higher profile (blow)
glareC and glareF	Severity of sun glare in the area where there is glare	Both	continuous and factor	0 = none, 1 = slight, 2 = moderate, 3 = severe
sightTime	Time of day sighting initially detected	Both	continuous	6am-7pm, in decimal format (i.e., 3:30pm = 15.5)
size	Number of animals in the group	Both	continuous	1-1000 (plane); 1-45 (ship)
species	Name of species, when multiple species are pooled	Both	factor	Species name
subj	Subjective overall average quality of sighting conditions	Both	continuous	0 = poor, 1 = fair, 2 = moderate, 3 = good, 4 = excellent
swellHeight	Approximate height of the swell (m)	Ship	continuous	0-5 m (plane); 0-2.4 m (ship)
swimDir	Approximate direction the animal(s) are swimming towards relative to the track line	Ship	continuous	0-359°, in increments of 5°. 0° = swimming in same direction ship is traveling; 45° = swimming to the right perpendicular to track line; 180° = swimming in opposite direction of ship's travel; 275° = swimming to the left perpendicular to track line.
turb	Turbidity, subjective evaluation of the level of water clarity	Plane	factor	1 = moderately clear; 2 = turbid; 3 = very turbid
vizC and vizF	Description of the general visibility at the horizon	Ship	continuous and factor	0 = clear horizon; 1 = good horizon; 2 = thin haze; 3 = thick haze; 4 = bad obscured horizon

Table 4A. Description of aerial survey data within the truncation distances for each species. Descriptions includes: left and right truncation distance (Trunc Dist) in meters; numbers of groups detected on the primary track lines (additional animals on extra track lines in parentheses) by the aerial front team (n-front), and aerial back team (n-back); number of duplicate sightings (n-dups) detected on the primary track lines (additional animals on extra track lines in parentheses); and average group size (Ave SS) with its coefficient of variation (CV[Ave SS]) for sighting detected by the primary team on the primary track lines. Descriptions of the total pooled species group are in italics.

A. Aerial data

Species	Trunc Dist	n-front	n-back	n-dups	Ave SS	CV(Ave SS)
Harbor porpoise	0-300	64 (9)	70 (5)	22 (4)	2.27	0.19
Small dolphins	*0-300*	*55 (30)*	*33 (20)*	*18 (15)*	*13.73*	*0.25*
Atlantic white-sided dolphin (*Lagenorhynchus acutus*)		8 (7)	6 (4)	5 (3)	37.76	0.34
Common dolphin *Delphinus delphis*		40 (21)	22 (16)	9 (12)	10.57	0.26
Common or White-sided dolphin		7 (2)	5 (0)	4 (0)	7.36	0.67
Large dolphins	*0-400*	*24 (38)*	*15 (26)*	*11 (17)*	*4.56*	*0.32*
Bottlenose dolphin *Tursiops truncatus*		9 (14)	7 (9)	4 (5)	3.47	0.32
Risso's dolphin *Grampus griseus*		7 (8)	4 (6)	4 (5)	3.50	0.82
Pilot whale spp. *Globicephala spp*		7(16)	4 (11)	3 (7)	9.02	0.54
Striped dolphin		1 (0)	0 (0)	0 (0)	60.00	0.00
Large whales	*75-600*	*36 (9)*	*8 (6)*	*4 (4)*	*1.18*	*0.55*
Fin whale *Balaenoptera physalus*		4 (3)	1 (2)	0 (1)	1.24	0.12
Fin or Sei whale *B. physalus or B. borealis*		1 (1)	0 (1)	0 (0)	1.00	0.00
Humpback whale *Megaptera novaeangliae*		17 (1)	6 (0)	4 (0)	1.06	0.05
Minke whale *B. acutorostrata*		14 (4)	1 (3)	0 (3)	1.33	0.10

Table 4B. Description of shipboard survey data within the truncation distances for each species. Descriptions includes: left and right truncation distance (Trunc Dist) in meters; numbers of groups detected on the primary track lines (additional animals on extra track lines in parentheses) by the shipboard front team (n-upper, and lower team (n-back); number of duplicate sightings (n-dups) detected on the primary track lines (additional animals on extra track lines in parentheses); and average group size (Ave SS) with its coefficient of variation (CV[Ave SS]) for sighting detected by the primary team on the primary track lines. Descriptions of the total pooled species group are in italics.

B. Shipboard data

Species	Trunc dist	n-upper	n-lower	n-dups	Ave SS	CV(Ave SS)
Fin or Sei whales	*0-6000*	*134*	*125*	*63*	*1.6*	*0.04*
Blue whale (*Balaenoptera musculus*)		3	3	2	1.0	0.00
Fin whale (*Balaenoptera physalus*)		107	115	58	1.7	0.05
Fin (*B. physalus*) or Sei whale (*B. borealis*)		18	5	1	1.4	0.11
Minke whale (*B. acutorostrata*)		2	0	0	1.0	0.00
Sei whale (*Balaenoptera borealis*)		4	2	2	2	0.29
Humpback whale (*Megaptera novaeangliae*)	0-8000	52	48	21	3.0	0.38
Sperm whale (*Physeter macrocephalus*)	0-3000	52	59	37	2.1	0.23
Bottlenose dolphin spp. (*Tursiops truncatus*)	0-3000	79	72	48	10.5	0.08
Common and White-sided dolphins	*0-3000*	*87*	*79*	*56*	*57.7*	*0.11*
Atlantic white-sided dolphin (*Lagenorhynchus acutus*)		2	2	2	13.5	0.41
Common dolphin (*Delphinus delphis*)		85	77	54	58.5	0.11
Stenella spp	*0-5000*	*67*	*73*	*53*	*38.5*	*0.08*
Atlantic spotted dolphin (*Stenella attenuata*)		12	15	12	27.2	0.17
Striped dolphin (*Stenella coeruleoalba*)		55	58	41	40.1	0.08
Risso's dolphin (*Grampus griseus*)	0-3000	124	130	78	7.6	0.08
Blackfish	*0-3500*	*68*	*72*	*46*	*9.4*	*0.07*
False killer whale (*Pseudorca crassidens*)		3	4	3	11.5	0.55
Pilot whales spp. (*Globicephala spp*)		65	68	43	9.3	0.07
Beaked whales and Kogia spp.	*0-4000*	*105*	*110*	*40*	*2.4*	*0.06*
Blainville's beaked whale (*Mesoplodon densirostris*)		1	0	0	3.0	0.00
Cuvier's beaked whale (*Ziphius cavirostris*)		21	22	9	3.0	0.09
Gervais' beaked whale (*Mesoplodon europaeus*)		4	6	2	3.8	0.28
Sowerby's beaked whale (*Mesoplodon bidens*)		2	4	1	3.8	0.21
True's beaked whale (*Mesoplodon mirus*)		5	3	2	3.0	0.17

Unidentified Mesoplodont	25	25	12	2.8	0.14
Unidentified Ziphiidae	23	26	7	1.9	0.09
Dwarf sperm whale (*Kogia simus*)	7	8	3	1.9	0.23
Pygmy sperm whale (*Kogia breviceps*)	6	2	1	1.0	0.00
Dwarf/pygmy sperm whale	11	14	3	1.4	0.12

Table 5A. Aerial survey intermediate parameters from the mark-recapture distance sampling (MRDS) analysis in the independent observer (IO) configuration assuming point independence by using data from both teams in area of overlap and the multicovariate distance sampling analysis from only the primary team. The following are included: key model and significant covariates; Cramer-von Mises goodness-of-fit test p-value (C-vM p-value); effective half strip width (ESHW) and its coefficient of variation [cv(eshw)], measured in meters; and the average probability of detecting an animal group on the track line by the primary team [p(0)] and its coefficient of variation [cv(p(0))].

Species	Team	Key Model	Distance Sampling Covariates (DS)	Mark-recapture Covariates (MR)	C-vM test p-value	ESHW (m)	CV (ESHW)	Ave p(0) Primary Team	CV(p(0))
Harbor porpoise	IO	HAZ	distance+sightTime+size	team * (distance + cloudcov)	0.88	-	-	0.47	0.23
	back	HN	distance+sightTime+size	NA	0.89	109	0.03	-	-
Bottlenose dolphin, Risso's dolphin, Pilot whale	IO	HN	distance + beaufort	team * (distance + sightTime)	0.61	-	-	0.60	0.31
	back	HN	distance + species	NA	0.33	130	0.32	-	-
Fin whale, Fin or Sei whale, Humpback whale, Minke whale	IO	HAZ	distance+sightTime	(team * distance) + sightTime + swmdir	0.82	-	-	0.68	0.45
	front	HAZ	distance + subj + glareC	NA	0.50	323	0.16	-	-
Atlantic white-sided dolphin, Common dolphin, Common/white-sided dolphin	IO	HAZ	distance + cloudcov + beaufort + subj	team*(distance + size + turb)	0.99	-	-	0.43	0.29
	back	HAZ	distance + cue + beaufort + cloudcov	NA	0.99	179	0.12	-	-

Table 5B. Shipboard survey intermediate parameters from the mark-recapture distance sampling (MRDS) analysis in the independent observer configuration assuming point independence. The following are included: key model and significant covariates; Cramer-von Mises goodness-of-fit test p-value (C-vM p-value; effective half strip width (ESHW) and its coefficient of variation [cv(eshw)], measured in meters; and the average probability of detecting an animal group on the track line by the upper primary team [p(0)] and its coefficient of variation [cv(p(0))].

Species	Key Model	Distance Sampling Covariates (DS)	Mark-recapture Covariates (MR)	C-vM test p-value	ESHW(m)	CV (ESHW)	Ave p(0) Primary Team	CV(p(0))
Fin, Sei, Fin/sei, Minke, Blue whales	HAZ	distance + size + cue	team*(distance + cue + size + subj)	0.86	1715	0.18	0.55	0.14
Humpback whale	HAZ	distance + beaufort + swellHeight + subj	distance + glareC	0.97	2995	0.16	0.54	0.19
Sperm whale	HAZ	distance + swmDir + vizF	distance + size + beaufort + glareC	0.29	2195	0.06	0.76	0.11
Bottlenose dolphin spp.	HAZ	distance + VizC + cloudcov	distance + glareF + size + cloudcov	0.97	1415	0.17	0.70	0.12
Common, White-sided dolphins	HAZ	distance + size + cue + beaufort	distance + size + swellHeight+glareC	0.62	1766	0.13	0.64	0.14
Risso's dolphin	HAZ	distance + beaufort + vizC + swimDir	distance + size + glareF + swellHeight	0.49	1119	0.30	0.64	0.16
Pilot whales spp., False killer whales	HAZ	distance + size + sightTime + swmDir	distance + size + glareC	0.81	1292	0.22	0.70	0.12
Striped, Atlantic spotted dolphins	HAZ	distance + size + behav	distance + size + beaufort + sightTime	0.65	1185	0.26	0.74	0.09
Beaked whales, Kogia spp.	HAZ	distance + swellHeight + glareF	distance + size + vizF	0.84	1071	0.23	0.45	0.22

Table 6. Availability bias correction factor (and coefficient of variation) for aerial and shipboard line transect data. Derived from Palka et al. (2017).

	Aerial		Ship	
Species	factor	CV (factor)	factor	CV (factor)
Bottlenose dolphin (*Tursiops truncatus*)	1.274	0.364	1	-
Common dolphin (*Delphinus delphis*)	1.075	0.138	1	-
Cuvier's beaked whale (*Ziphius cavirostris*)	7.042	0.462	1.309	0.246
Fin whale (*Balaenoptera physalus*)	2.674	0.336	1	-
Harbor porpoise (*Phocoena phocoena*)	1.592	0.299	1	-
Humpback whale (*Megaptera novaeangliae*)	1.541	0.185	1	-
Long/short finned pilot whale (*Globicephala melaena/ G. macrorhynchus*)	1.473	0.241	1	-
Minke whale (*B. acutorostrata*)	3.257	0.397	1	-
Pygmy/dwarf sperm whale (*Kogia spp*)	-	-	1.855	0.307
Risso's dolphin (*Grampus griseus*)	1.176	0.173	1	-
Right whale (*Eubalaena glacialis*)	3.774	0.06	1	-
Sei whale (*Balaenoptera borealis*)	2.398	0.517	1	-
Sperm whale (*Physeter macrocephalus*)	6.897	0.005	1.631	0.247
Striped dolphin (*Stenella coeruleoalba*)	1	0	1	-
White-sided dolphin (*Lagenorhynchus acutus*)	1.124	0.186	1	-

Table 7. Intermediate abundance estimates (N) and coefficient of variation [CV(N)] used in Equation 1 for each stratum and the species groupings with ambiguous identified sightings.

	Gulf of Maine		Shelf		Offshore		TOTAL	
Species	N	CV(N)	N	CV(N)	N	CV(N)	N	CV(N)
Fin whale (*Balaenoptera physalus*)	695	0.93	1,443	0.43	0	0	2,138	0.42
Sei whale (*Balaenoptera borealis*)	24	0.95	25	0.61	0	0	49	0.56
Fin or Sei whale	115	1.20	141	0.53	0	0	256	0.61
TOTAL fin and sei whales	834	0.79	1,609	0.39	0	0	2,442	0.37
Blainsville's beaked whale (*Mesoplodon densirostris*)	0	0	19	1.05	0	0	19	1.05
Cuvier's beaked whale (*Ziphius cavirostris*)	0	0	809	0.41	3,088	0.58	3,897	0.47
Gervais' beaked whale (*Mesoplodon europaeus*)	0	0	40	1.04	1,585	0.53	1,625	0.52
Sowerby's beaked whale (*Mesoplodon bidens*)	0	0	209	0.56	0	0	209	0.56
True's beaked whale (*Mesoplodon mirus*)	0	0	102	0.93	561	0.71	663	0.62
Unidentified Mesoplodon	0	0	707	0.47	3,537	0.51	4,244	0.43
Unidentified Ziphiidae	0	0	591	0.33	3,164	0.50	3,755	0.42
TOTAL beaked whales	0	0	2,477	0.21	11,935	0.26	14,412	0.22
Dwarf sperm whale (*Kogia simus*)	0	0	16	1.06	1,832	0.91	1,848	0.90
Pygmy sperm whale (*Kogia breviceps*)	0	0	38	0.78	562	1.07	600	1.00
Dwarf or Pygmy sperm whale	0	0	242	0.57	1,858	0.92	2,100	0.82
TOTAL Kogia spp.	0	0	296	0.48	4,252	0.58	4,548	0.49
Common dolphin (*Delphinus delphis*)	39,701	0.47	36,193	0.44	479	0.95	76,373	0.32
Atlantic white-sided dolphin (*Lagenorhynchus acutus*)	28,981	0.66	0	0	0	0	28,981	0.66
Common or White-sided dolphin	6,669	0.89	0	0	0	0	6,669	0.89
TOTAL common and white-sided dolphins	75,351	0.36	17,066	0.47	479	0.95	112,140	0.28

Table 8. Final abundance estimates(N) and their coefficient of variation [CV(N)] from the Northeast Fisheries Science Center's shipboard (Shelf and Offshore) and aerial (Gulf of Maine) surveys conducted June – September 2016 in waters north of North Carolina, for each stratum and the total of all strata.

	Gulf of Maine		Shelf		Offshore		TOTAL	
Species	N	CV(N)	N	CV(N)	N	CV(N)	N	CV(N)
Harbor porpoise (*Phocoena phocoena*)	75,079	0.38	0	0	0	0	75,079	0.38
Atlantic white-sided dolphin (*Lagenorhynchus acutus*)	31,795	0.61	117	0.74	0	0	31,912	0.61
Common dolphin (*Delphinus delphis*)	43,555	0.43	36,193	0.44	479	0.95	80,227	0.31
Fin whale (*Balaenoptera physalus*)	809	0.82	1,581	0.39	0	0	2,390	0.38
Sei whale (*Balaenoptera borealis*)	24	0.95	28	0.55	0	0	52	0.53
Minke whale (*B. acutorostrata*)	2,802	0.81	0	0.00	0	0	2,802	0.81
Blue whale (*Balaenoptera musculus*)	0	0	39	0.64	0	0	39	0.64
Humpback whale (*Megaptera novaeangliae*)	1,372	0.70	996	0.59	0	0	2,368	0.48
Sperm whale (*Physeter macrocephalus*)	37	1.01	1,051	0.36	2,233	0.49	3,321	0.35
Bottlenose dolphin spp. (*Tursiops truncatus*)	7,061	0.78	5,358	0.25	4,576	0.37	16,995	0.35
Atlantic spotted dolphin (*Stenella attenuata*)	0	0	1,860	0.52	6,387	0.26	8,247	0.24
Striped dolphin (*Stenella coeruleoalba*)	60	0	9,036	0.32	33,777	0.30	42,873	0.25
Spinner dolphin (*Stenella longirostris*)	0	0	0	0.00	160	0	160	0.00
Risso's dolphin (*Grampus griseus*)	1,001	1.14	11,423	0.32	9,473	0.36	21,897	0.23
Pilot whales spp. (*Globicephala spp.*)	5,836	0.92	7,024	0.38	3,877	0.44	16,737	0.37
False killer whale (*Pseudorca crassidens*)	0	0	0	0.00	1,182	0.63	1,182	0.63
Blainsville's beaked whale (*Mesoplodon densirostris*)	0	0	55	0.47	0	0	55	0.47
Cuvier's beaked whale (*Ziphius cavirostris*)	0	0	1,062	0.33	4,202	0.45	5,264	0.37
Gervais' beaked whale (*Mesoplodon europaeus*)	0	0	117	0.46	5,711	0.31	5,828	0.30
Sowerby's beaked whale (*Mesoplodon bidens*)	0	0	703	0.29	0	0	703	0.29
True's beaked whale (*Mesoplodon mirus*)	0	0	540	0.43	2,022	0.34	2,562	0.28
Dwarf sperm whale (*Kogia simus*)	0	0	141	0.93	3,254	0.65	3,395	0.62
Pygmy sperm whale (*Kogia breviceps*)	0	0	155	0.48	998	0.72	1,153	0.63
TOTAL	169,432	0.24	77,479	0.23	78,331	0.44	325,242	0.19

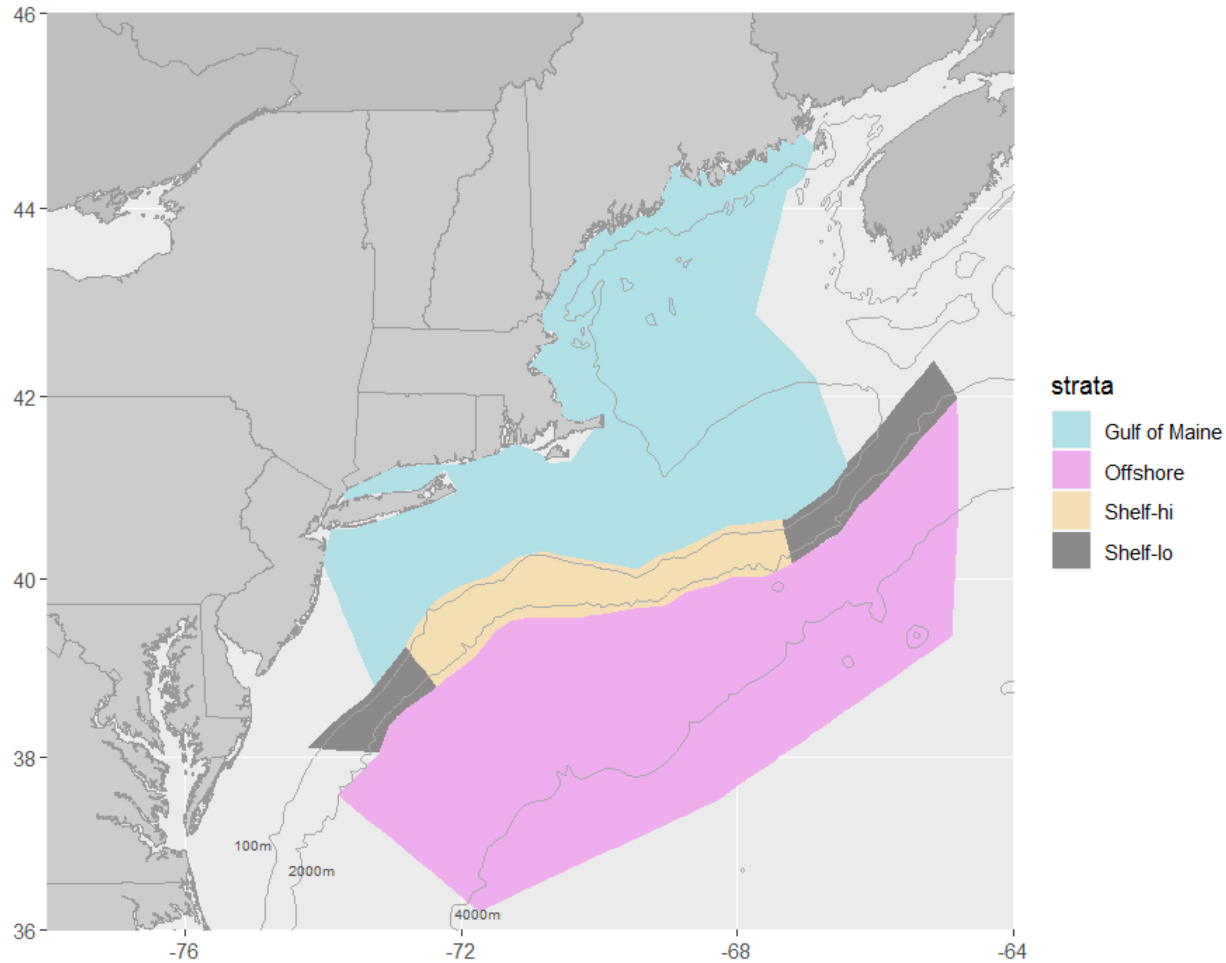

Figure 1. Strata locations of the Northeast Fisheries Science Center's shipboard and aerial abundance surveys during summer 2016.

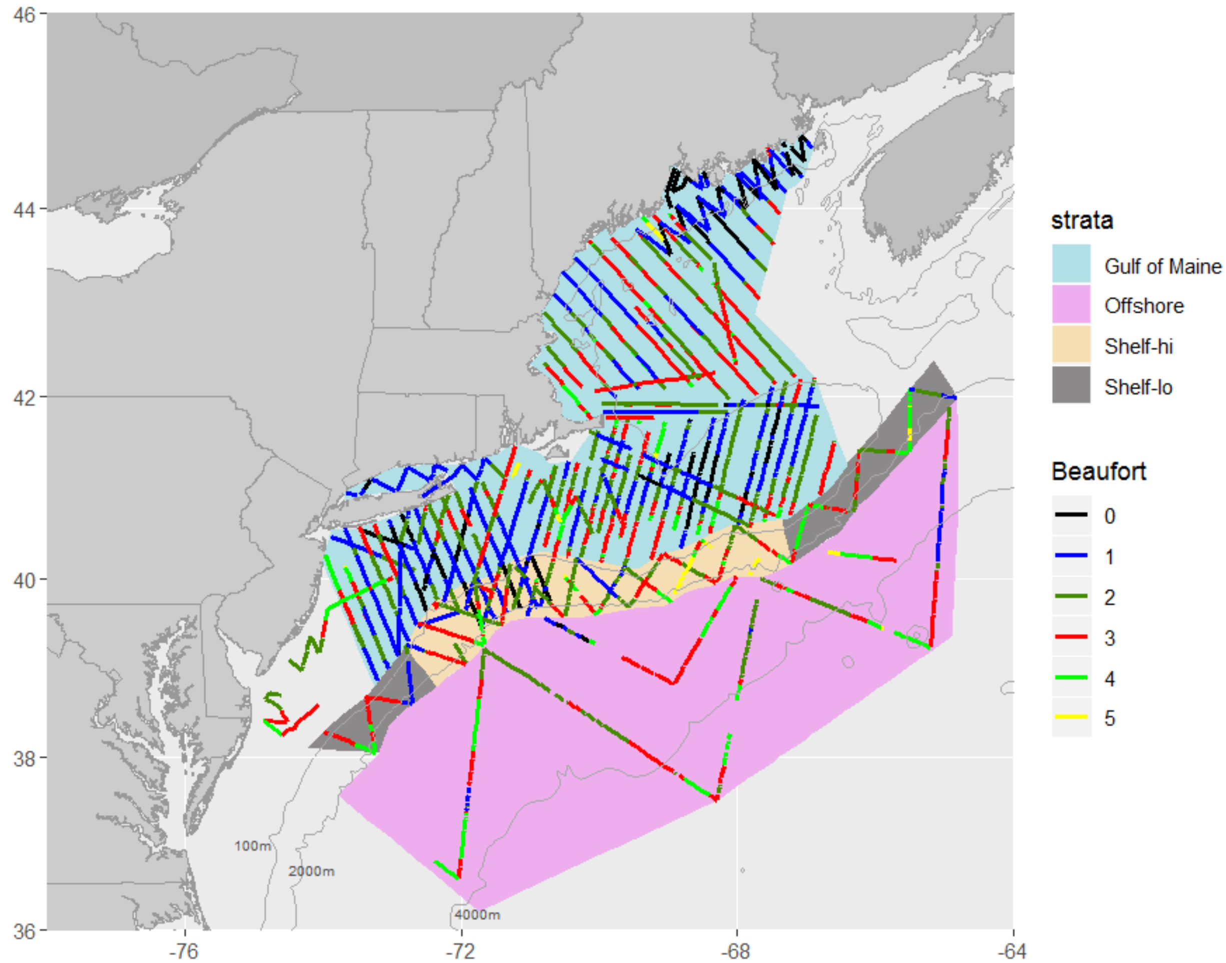

Figure 2. On-effort track lines (lines) within the primary strata (colored polygons) where colors of track lines indicated the Beaufort sea state encountered while on that portion of the track lines

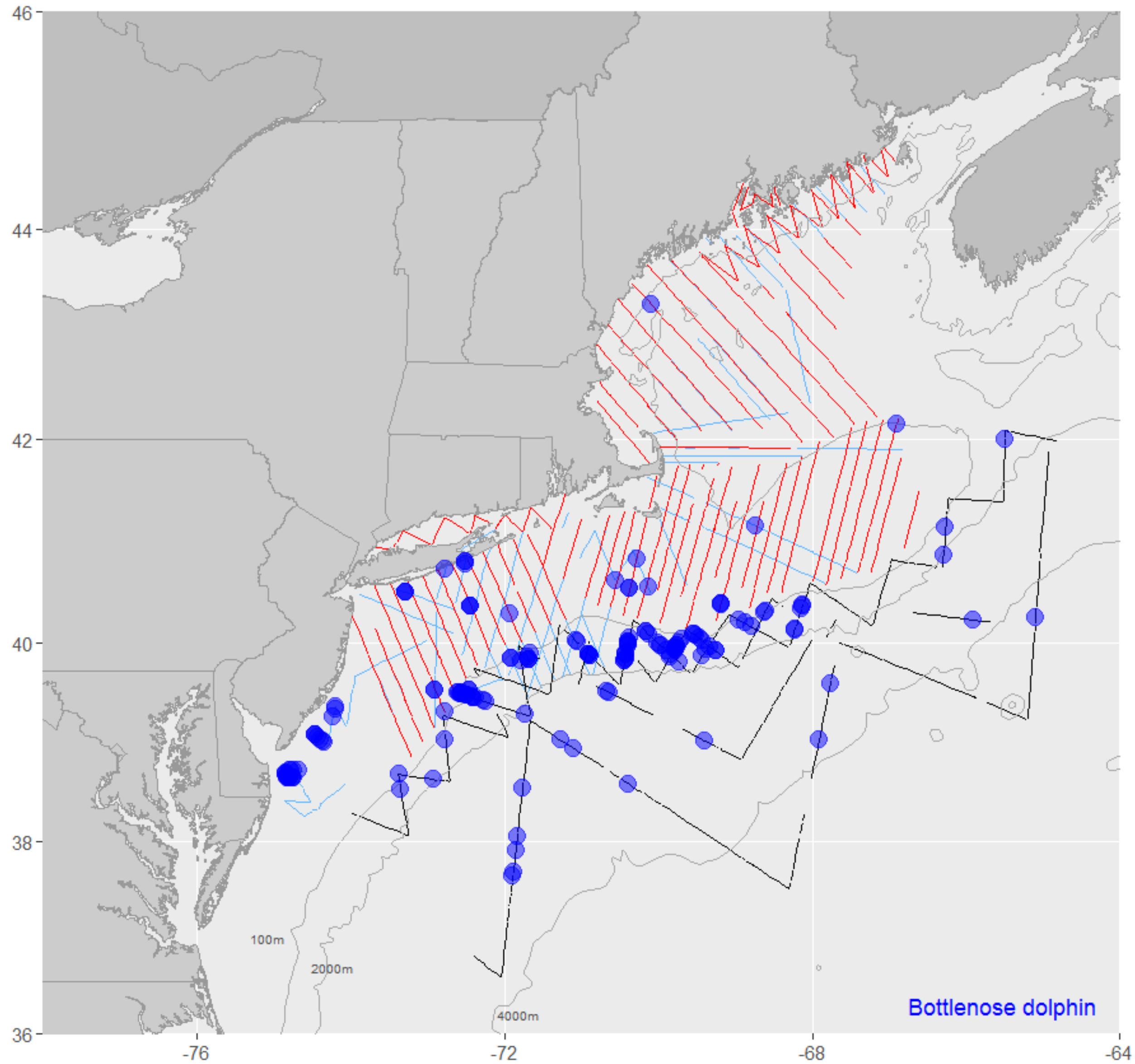

Figure 3. Bottlenose dolphin (*Tursiops truncatus*) sighting locations. Red aerial track lines. Black shipboard track lines. Blue extra track lines.

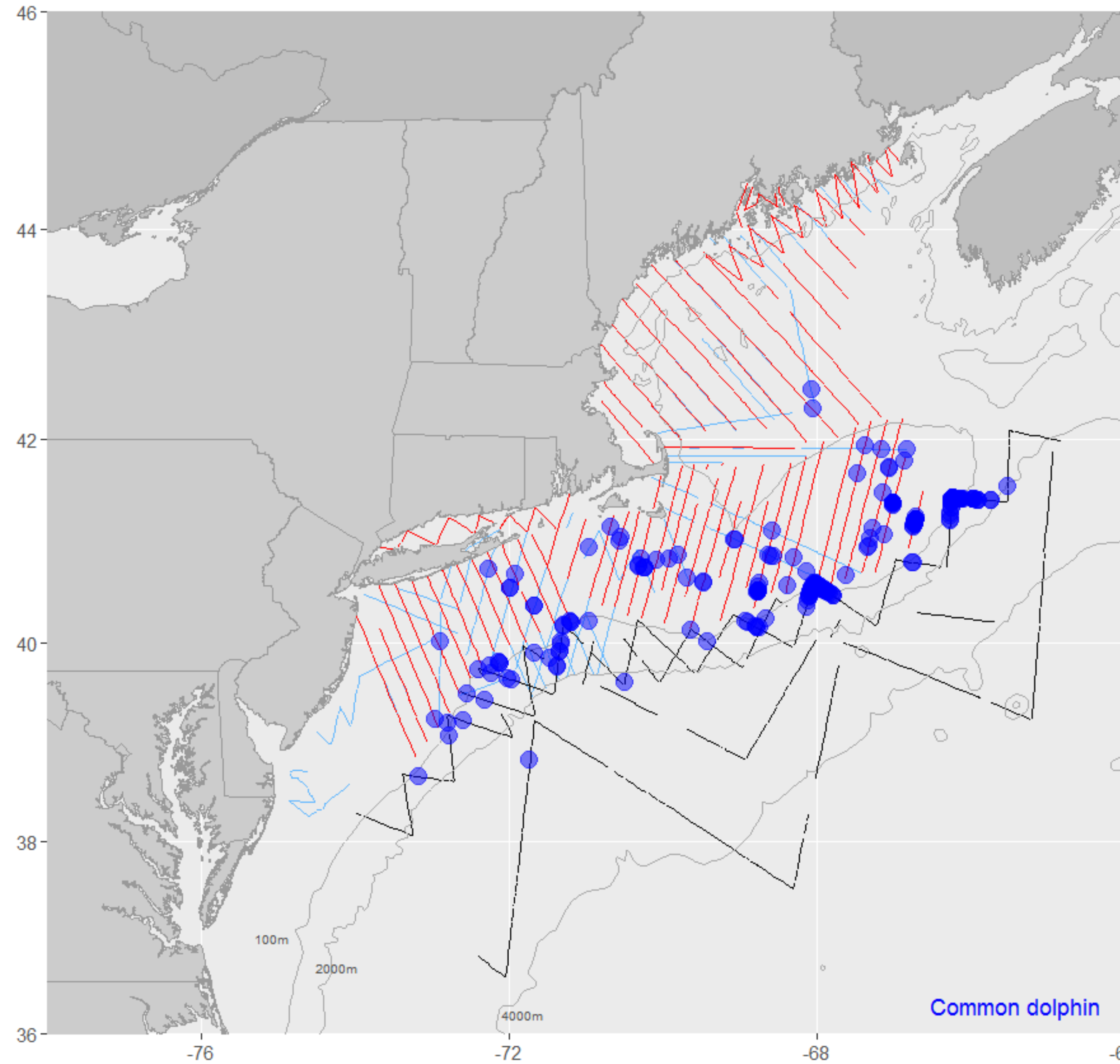

Figure 4. Short-beaked common dolphin (*Delphinus delphis*) sighting locations. Red aerial track lines. Black shipboard track lines. Blue extra track lines.

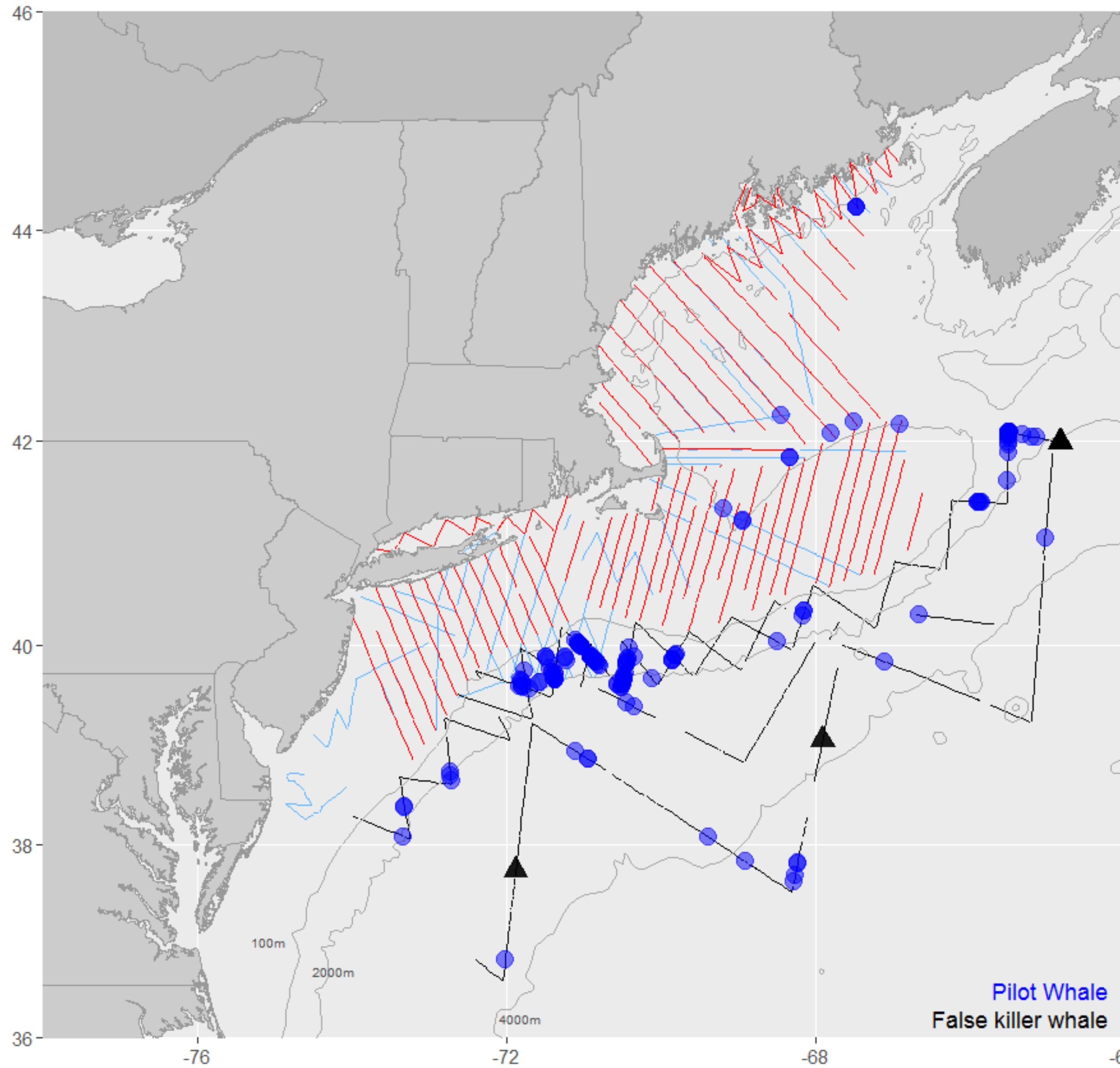

Figure 5. Pilot whale (Globicephala spp; blue circles) and False killer whale (*Pseudorca crassidens*; black triangles) sighting locations. Red aerial track lines. Black shipboard track lines. Blue extra track lines.

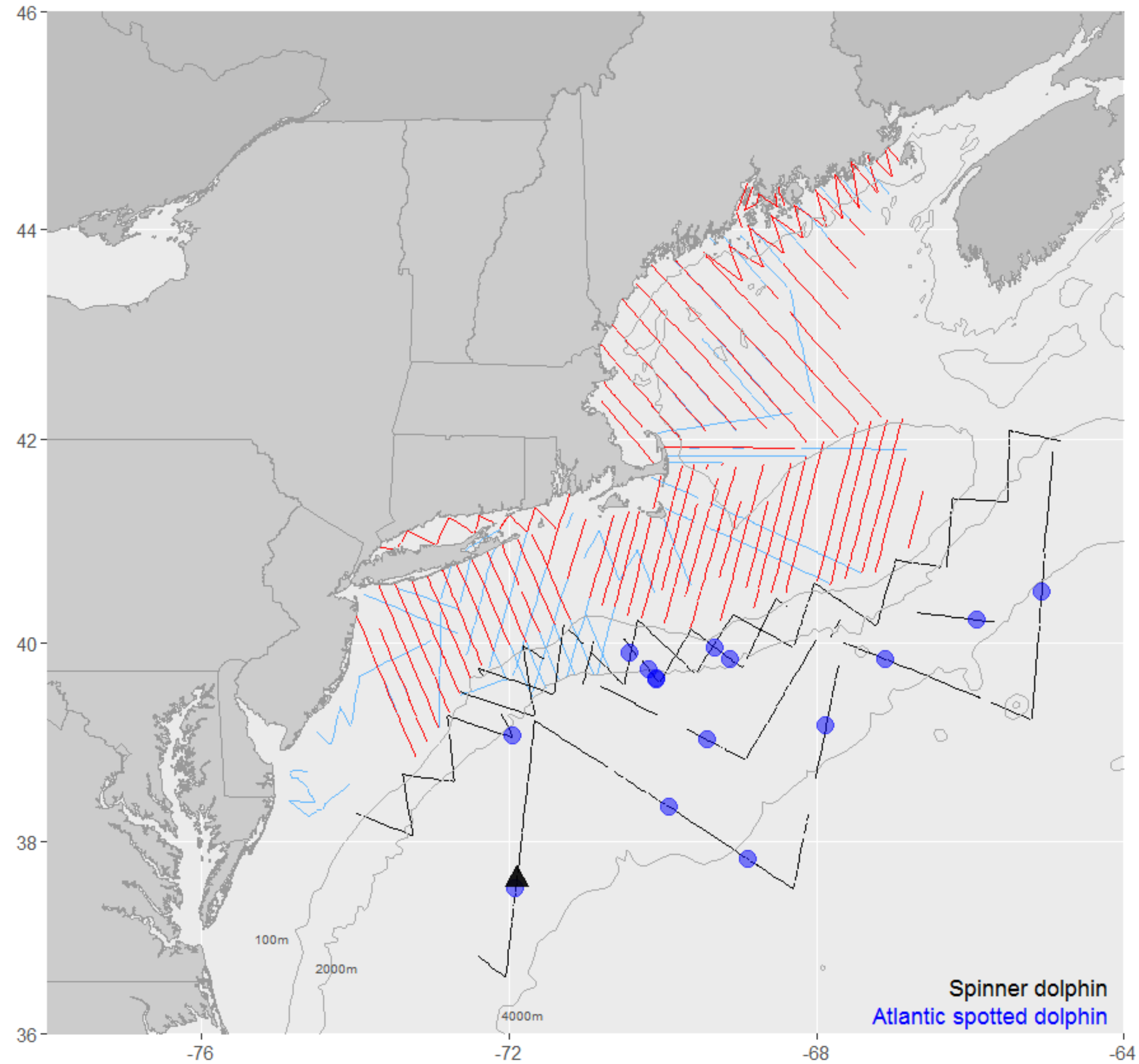

Figure 6. Spinner dolphin (*Stenella longirostris*; black) and Atlantic spotted dolphin (*Stenella attenuata*; blue) sighting locations. Red aerial track lines. Black shipboard track lines. Blue extra track lines.

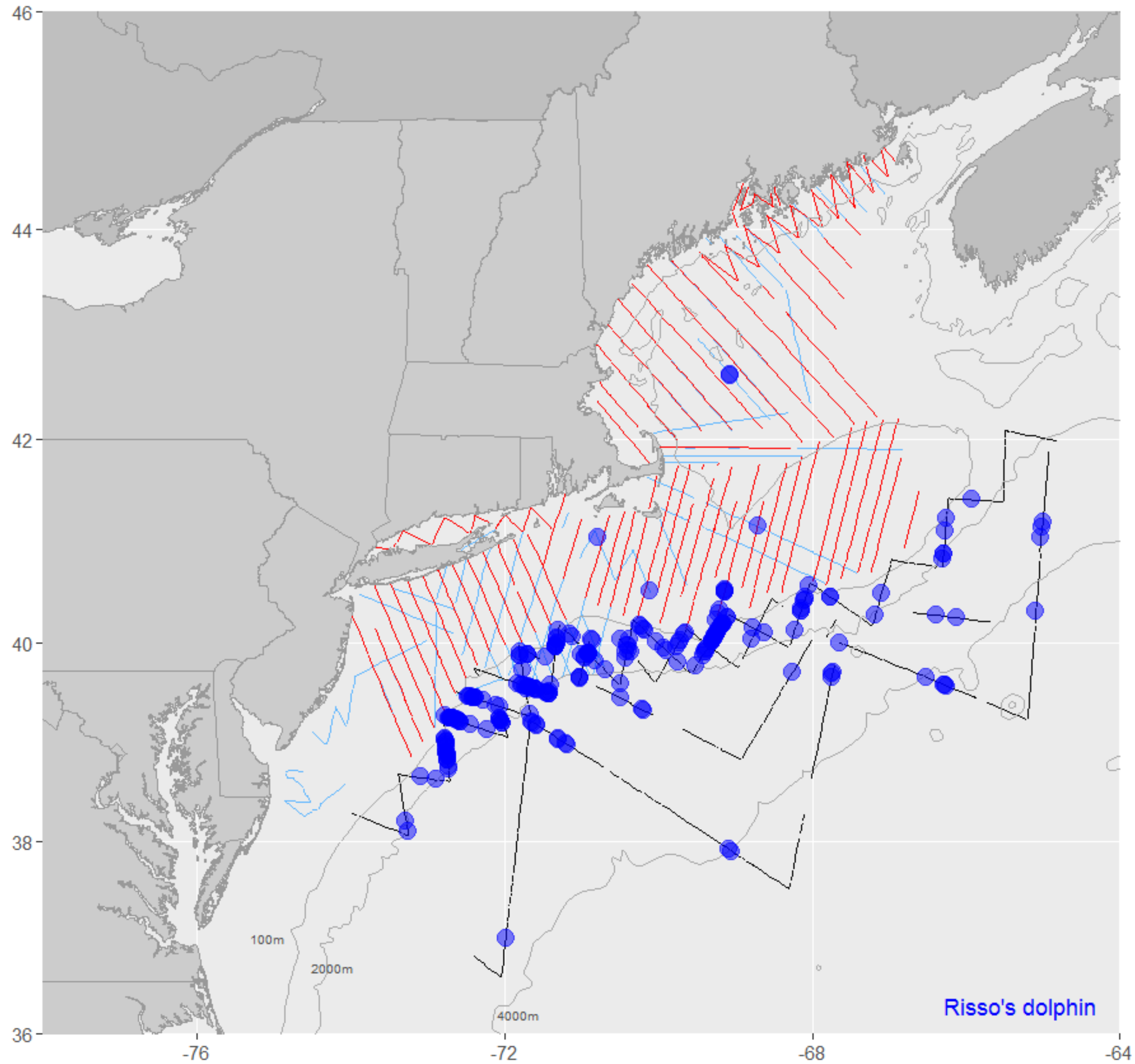

Figure 7. Risso's dolphin (*Grampus griseus*) sighting locations. Red aerial track lines. Black shipboard track lines. Blue extra track lines.

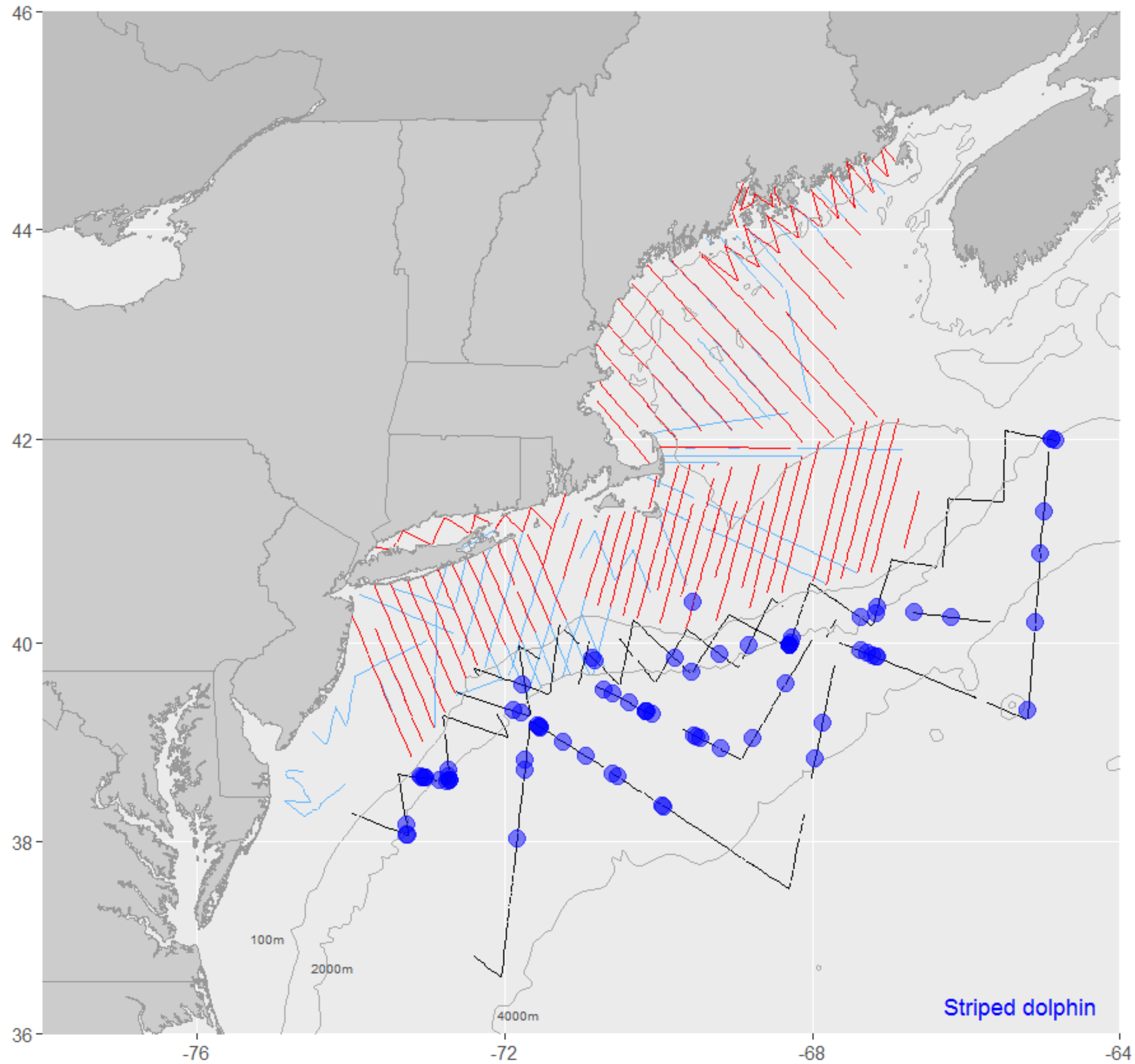

Figure 8. Striped dolphin (*Stenella coeruleoalba*) sighting locations. Red aerial track lines. Black shipboard track lines. Blue extra track lines.

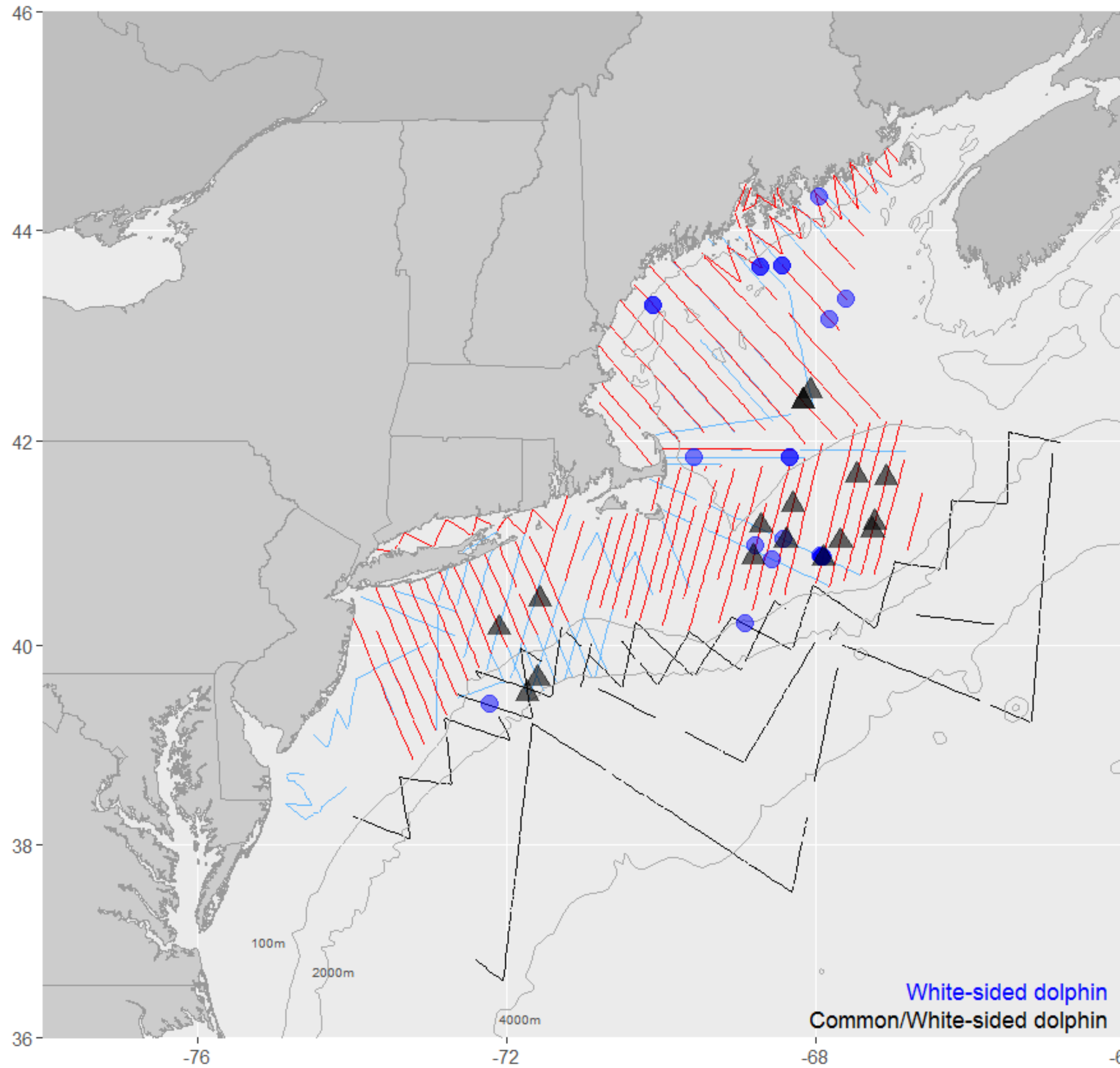

Figure 9. Atlantic White-sided dolphin (*Lagenorhynchus acutus*; blue circle) and ambiguous common dolphin (*Delphinus delphis*)/white-sided dolphin (black triangle) sighting locations. Red aerial track lines. Black shipboard track lines. Blue extra track lines.

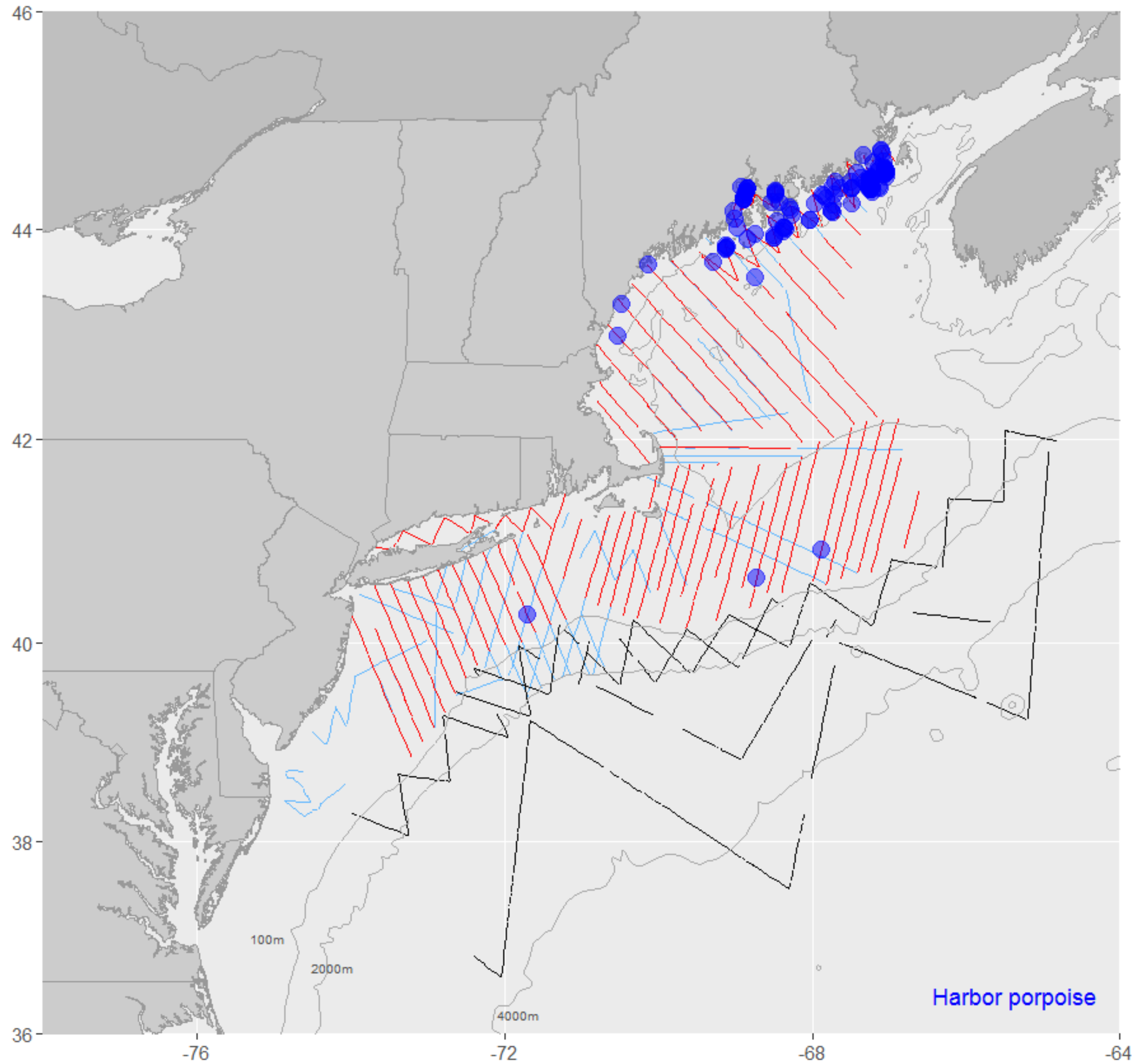

Figure 10. Harbor porpoise (*Phocoena phocoena*) sighting locations. Red aerial track lines. Black shipboard track lines. Blue extra track lines.

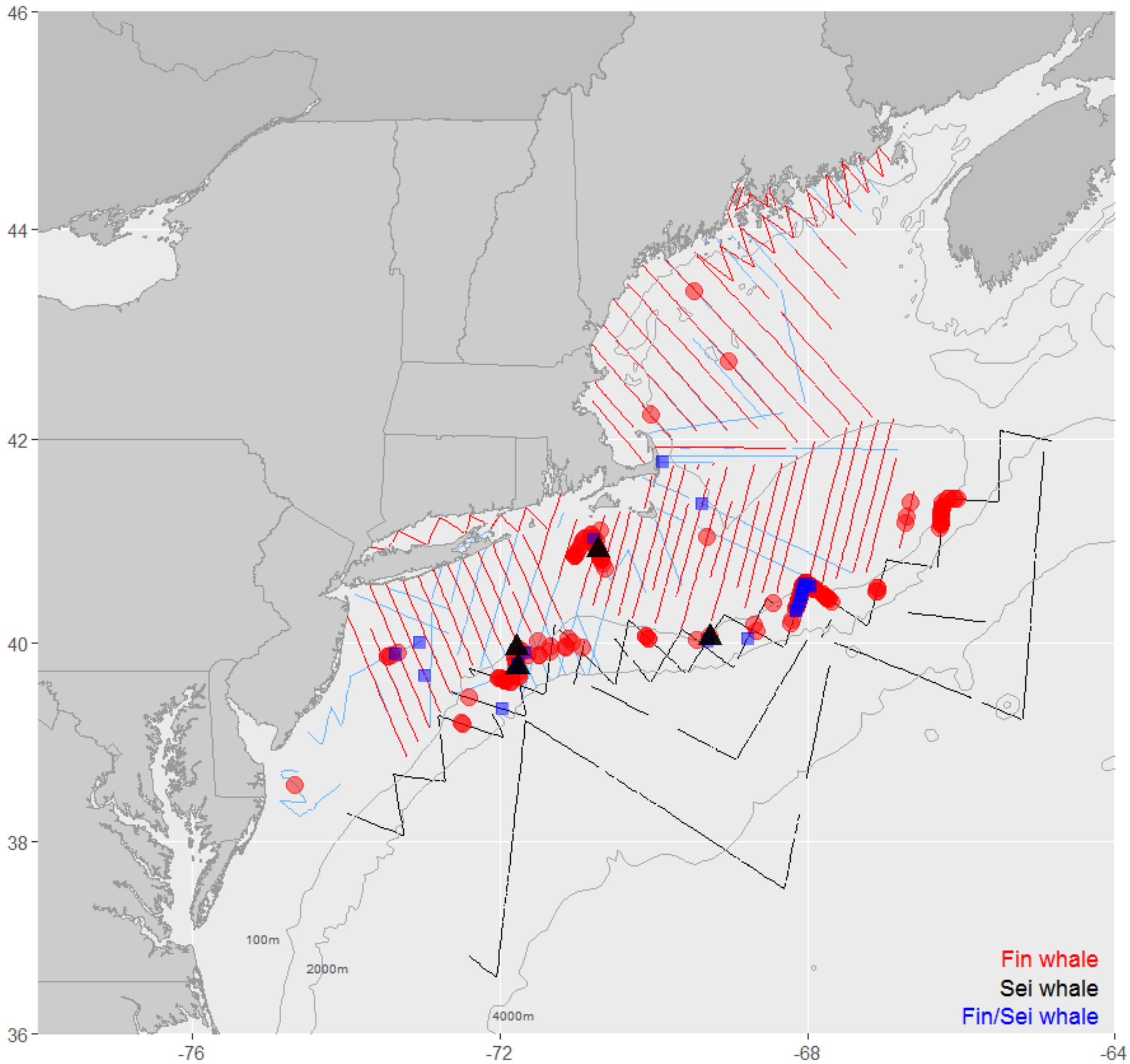

Figure 11. Fin whale (*Balaenoptera physalus*; red circle), sei whale (*Balaenoptera borealis*; black triangle) and fin/sei whale (blue square) sighting locations. Red aerial track lines. Black shipboard track lines. Blue extra track lines.

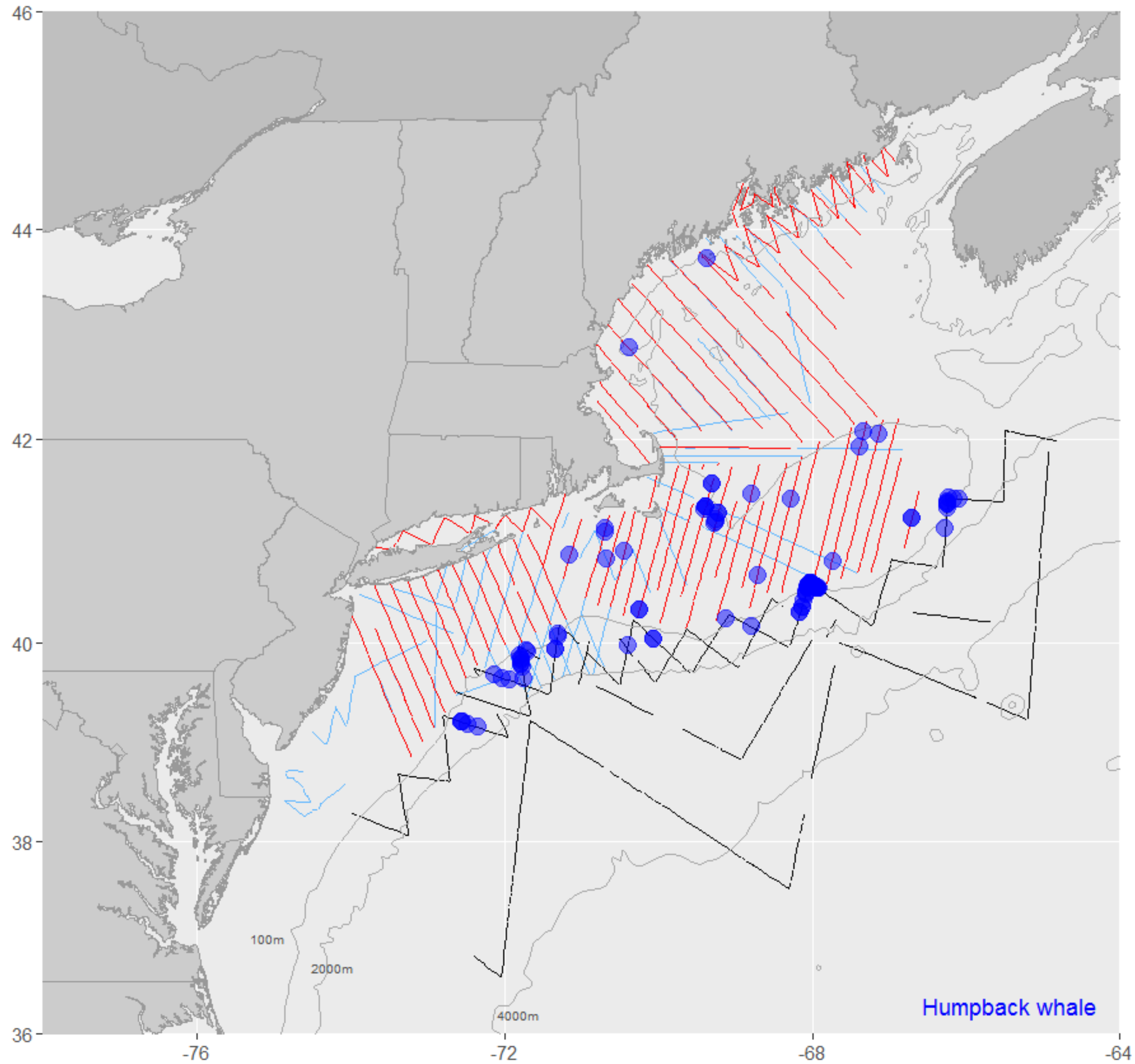

Figure 12. Humpback (*Megaptera novaeangliae*) whale sighting locations. Red aerial track lines. Black shipboard track lines. Blue extra track lines.

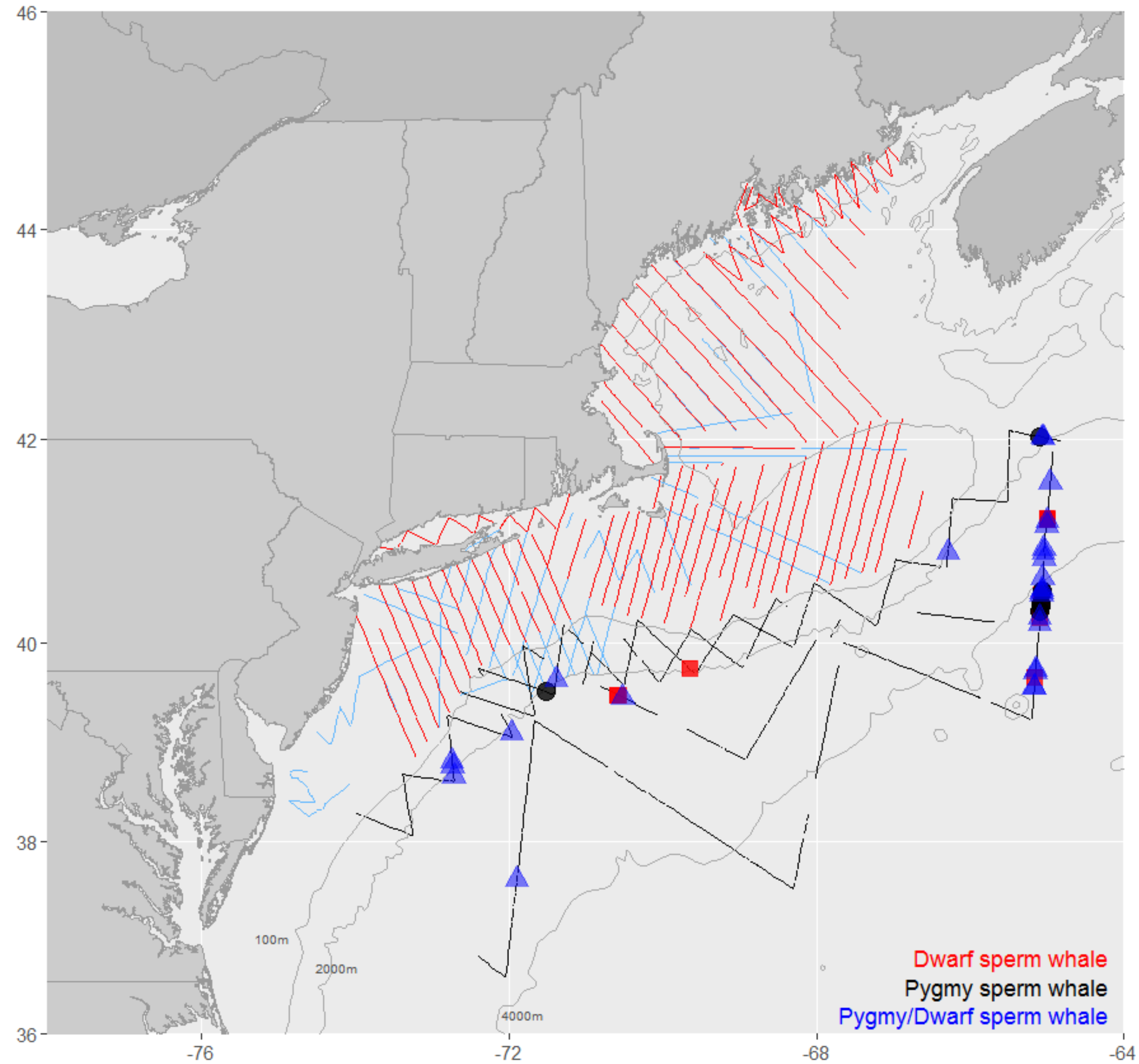

Figure 13. Dwarf sperm whale (*Kogia simus*; red square), pygmy sperm whale (*Kogia breviceps*; black circle), and pygmy/dwarf sperm whale (blue triangle) sighting locations. Red aerial track lines. Black shipboard track lines. Blue extra track lines.

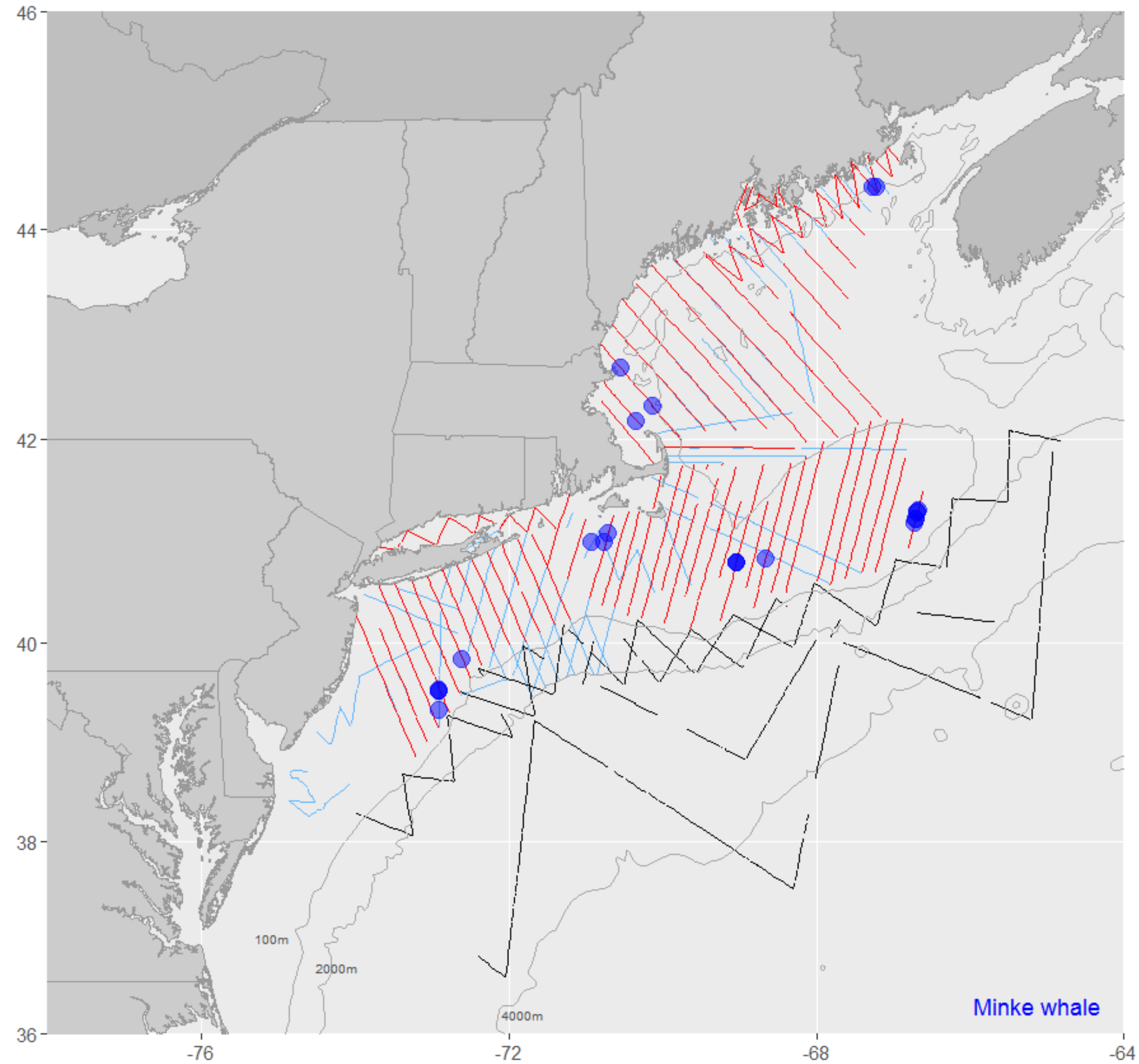

Figure 14. Minke whale (*Balaenoptera acutorostrata*) sighting locations. Red aerial track lines. Black shipboard track lines. Blue extra track lines.

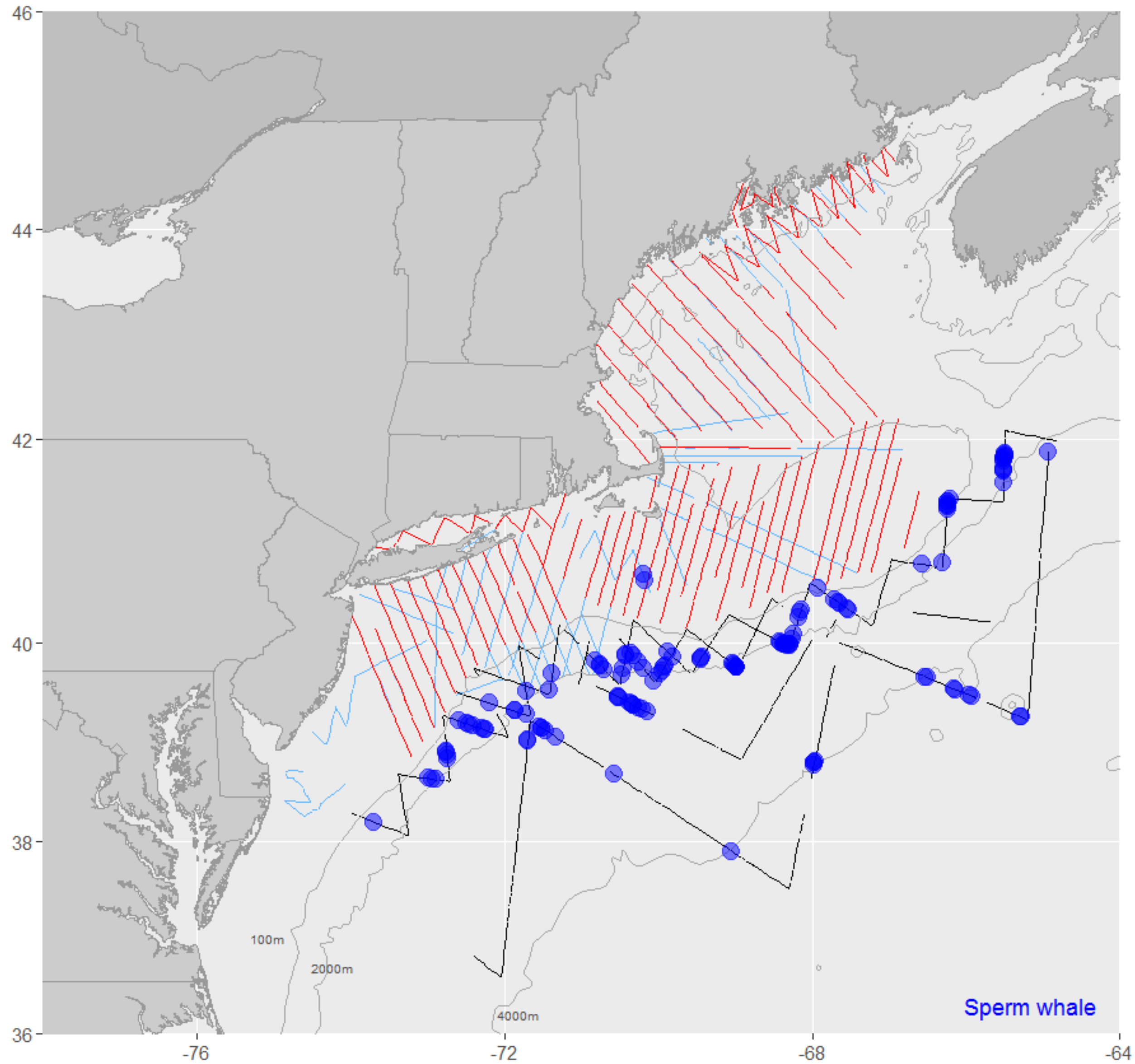

Figure 15. Sperm whale (*Physeter macrocephalus*) sighting locations. Red aerial track lines. Black shipboard track lines. Blue extra track lines.

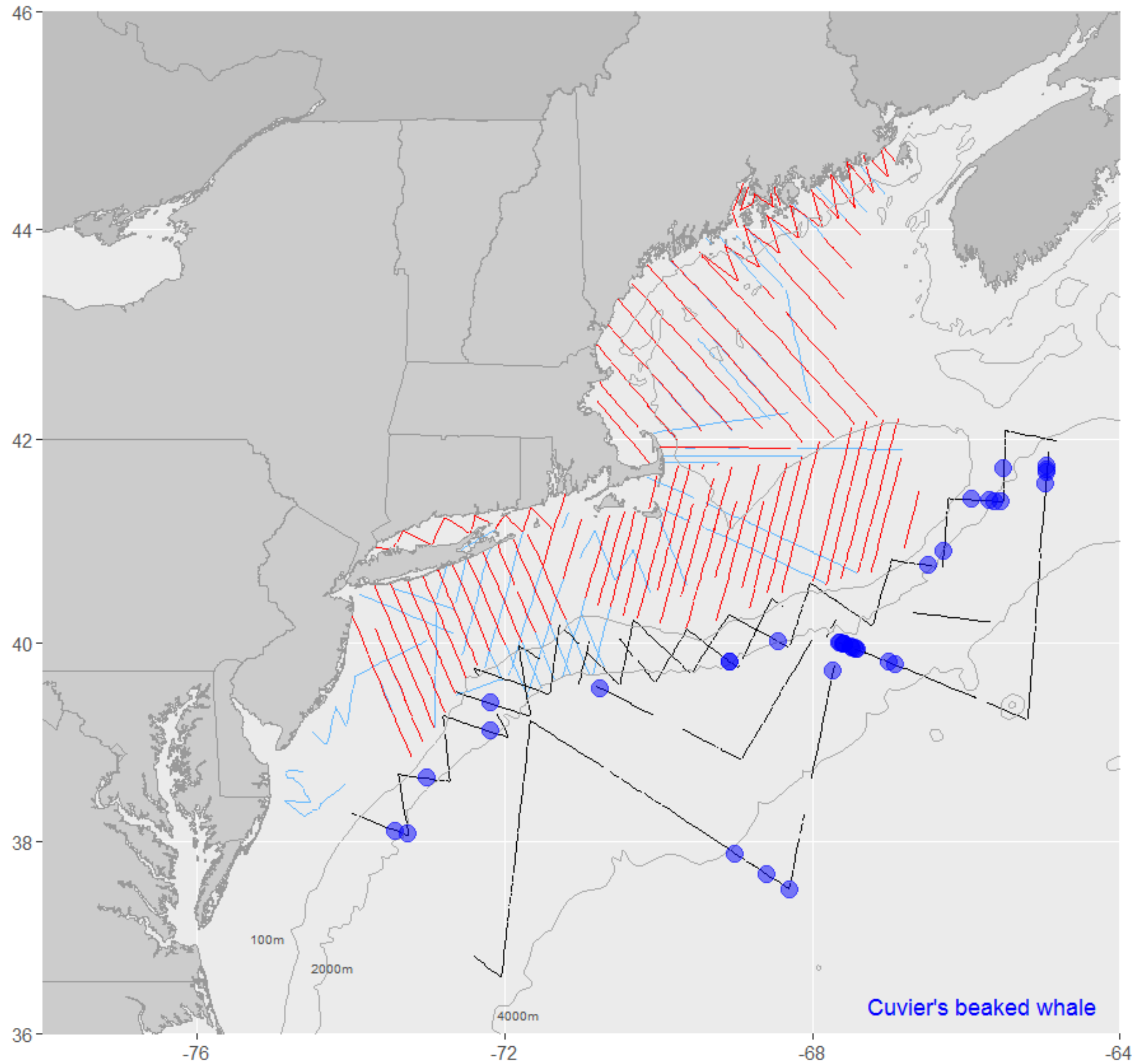

Figure 16. Cuvier's beaked whale (*Ziphius cavirostris*) sighting locations. Red aerial track lines. Black shipboard track lines. Blue extra track lines.

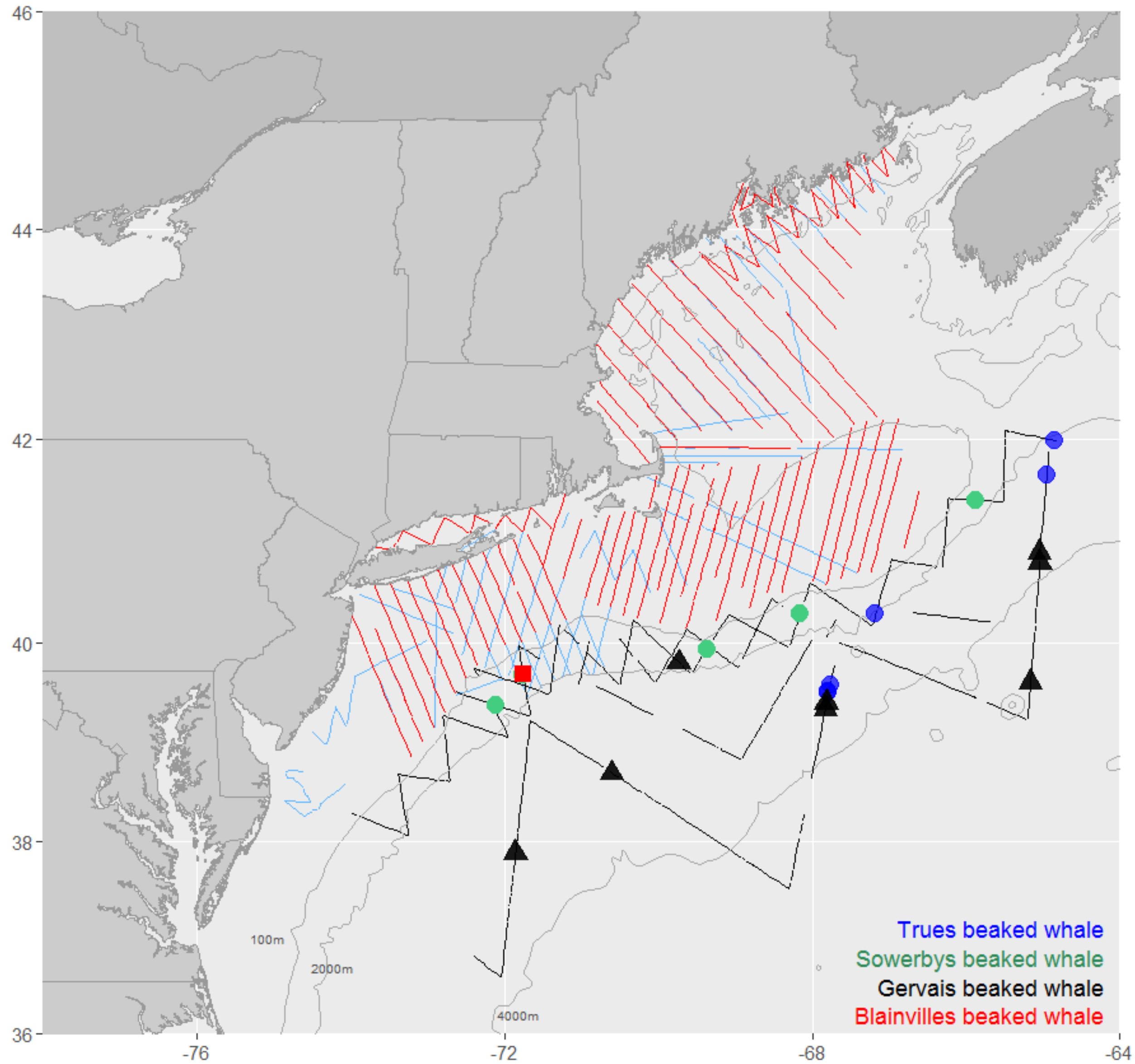

Figure 17. True's beaked whale (*Mesoplodon mirus*; blue circle), Sowerby's beaked whale (*Mesoplodon bidens*; green circle), Gervais' beaked whale (Mesoplodon *europacus*; black triangle), and Blainville's beaked whale (*Mesoplodon densirostris*; red square) sighting locations. Red aerial track lines. Black shipboard track lines. Blue extra track lines.

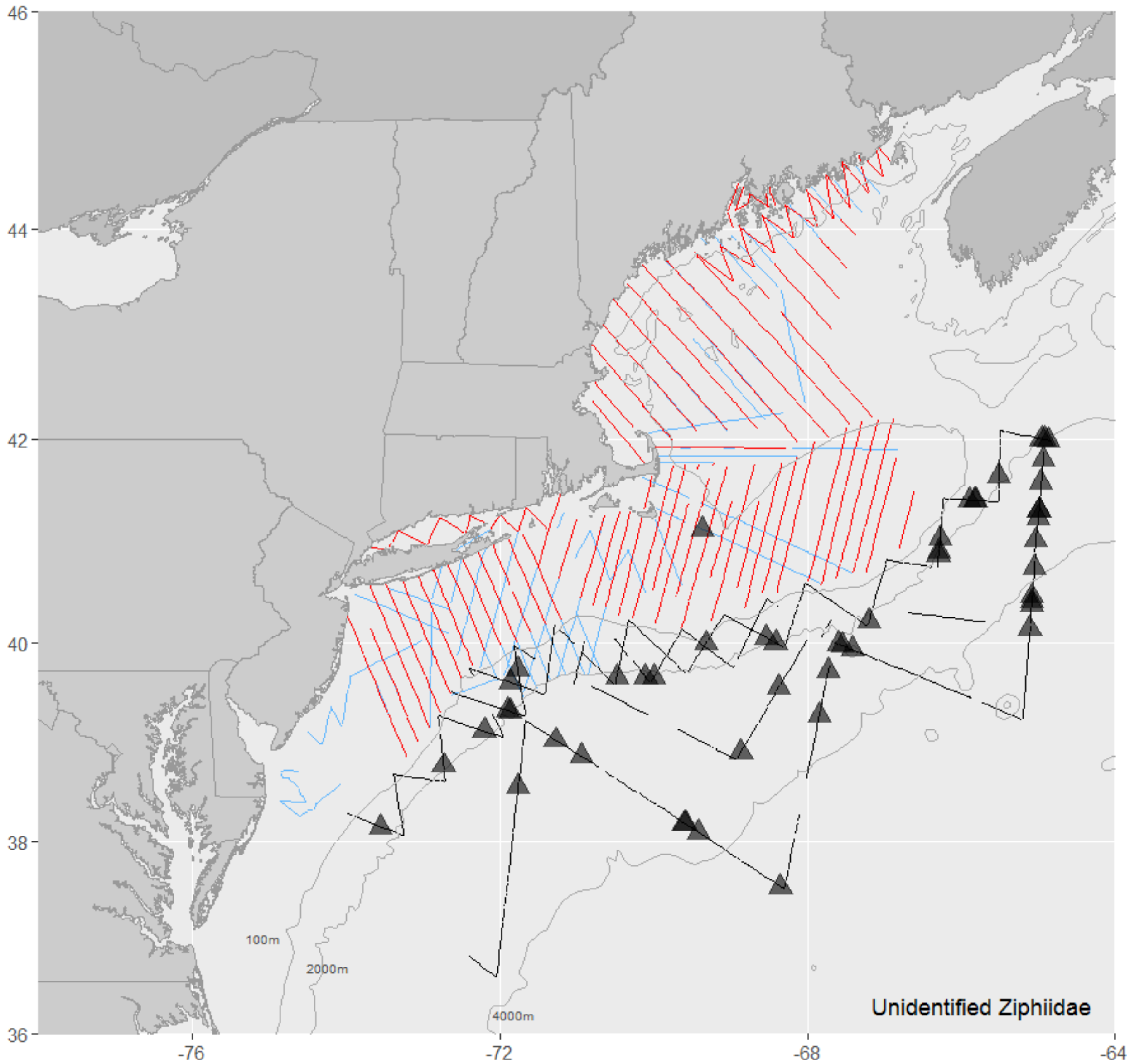

Figure 18. Unidentified Ziphiidae sighting locations. Red aerial track lines. Black shipboard track lines. Blue extra track lines.

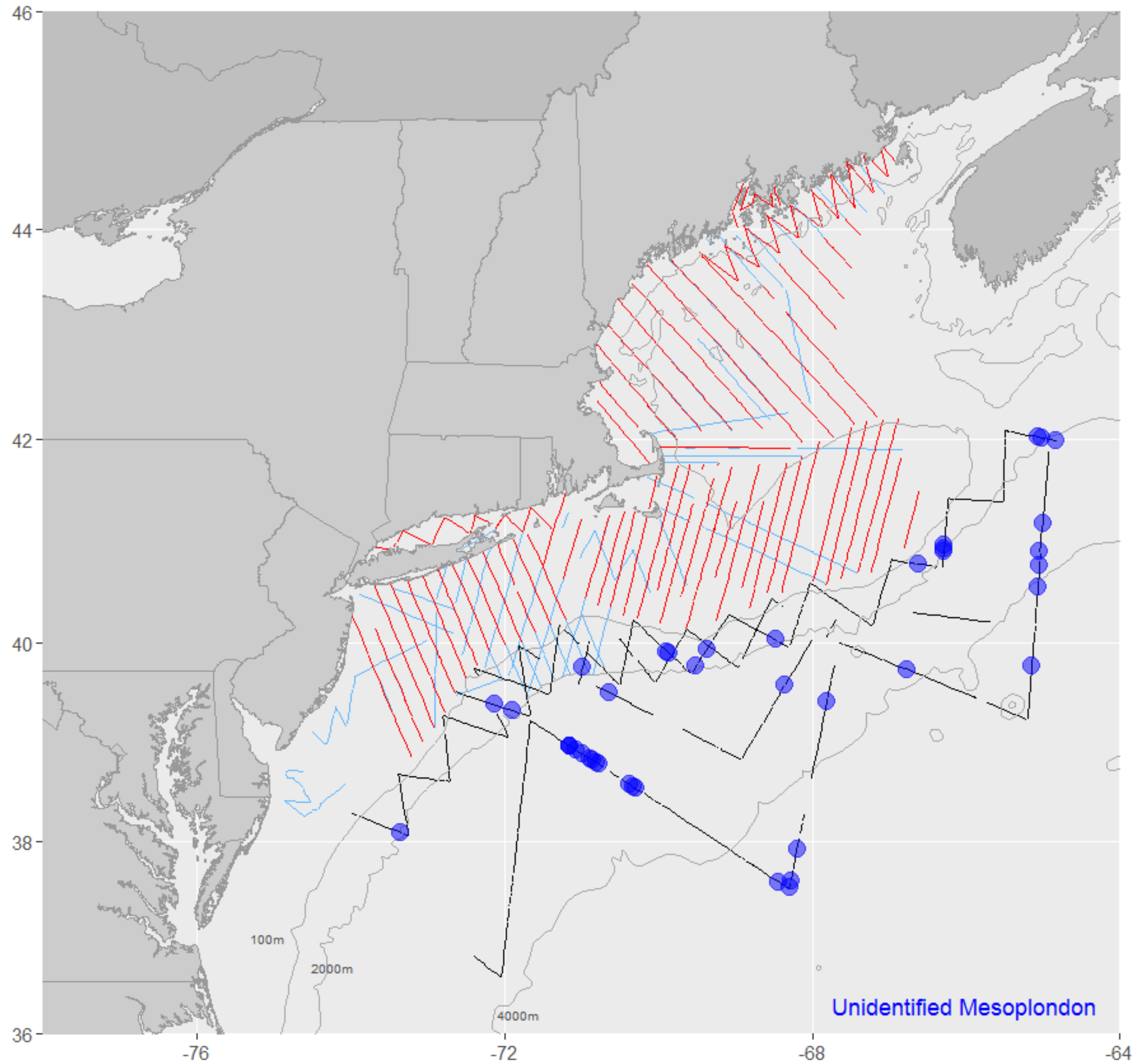

Figure 19. Unidentified Mesoplodon sighting locations. Red aerial track lines. Black shipboard track lines. Blue extra track lines.

APPENDIX A. DIAGNOSTIC PLOTS FOR EACH SPECIES GROUPING FOR THE AERIAL SURVEYS

For each species grouping, the front team is designated as "Observer 1" and the back team is "Observer 2" in the diagnostic plots that include the following:

A. A scaled histogram of front team's detections from the area of overlap with the back team; a line that is the average fitted distance sampling (DS) model scaled from the mark-recapture (MR) estimated g(0); and the points that are the estimated detection probability, given the covariate values and distance of each observation.
B. A scaled histogram of back team's detections from the area of overlap with the front team; a line that is the average fitted DS model scaled from the MR estimated g(0); and the points that are the estimated detection probability, given the covariate values and distance of each observation.
C. A scaled histogram of the pooled front and back teams' detections from the area of overlap; a line that is the average fitted DS model scaled from the MR estimated g(0); and the points that are the estimated detection probability, given the covariate values and distance of each observation.
D. A scaled histogram of the duplicate detections from the area of overlap; a line that is the average fitted DS model scaled from the MR estimated g(0); and the points that are the estimated detection probability, given the covariate values and distance of each observation.
E. The conditional MR detection probability (prob.) function for the front team, given detection by the back team in the area of overlap; a histogram of the proportion of sightings seen by the front team, given they were seen by the back team; the fitted MR model averaged over covariate values; and points for each estimated detection probability for each observation.
F. The conditional MR detection probability (prob.) function for the back team, given detection by the front team in the area of overlap; a histogram of the proportion of sightings seen by the back team, given they were seen by the front team; the fitted MR model averaged over covariate values; and points for each estimated detection probability for each observation.
G. A quantile-quantile (Q-Q) plot showing the goodness of fit of the independent observer MRDS fitted versus empirical cumulative distribution function (cdf) for data in the area of overlap.
H. A scaled histogram of the detections from only the primary team, as defined in the text when used in the step 2 multiple covariate distance sampling (MCDS) analysis; a line giving the detection function averaged over the estimated population levels of the covariate values; points for each observation at its estimated detection probability, given the observation's covariate values and distance.
I. A quantile-quantile (Q-Q) plot showing the goodness of fit of the MCDS fitted versus empirical cumulative distribution (cdf) function from the step 2 analysis that was estimated from only the primary team's data.

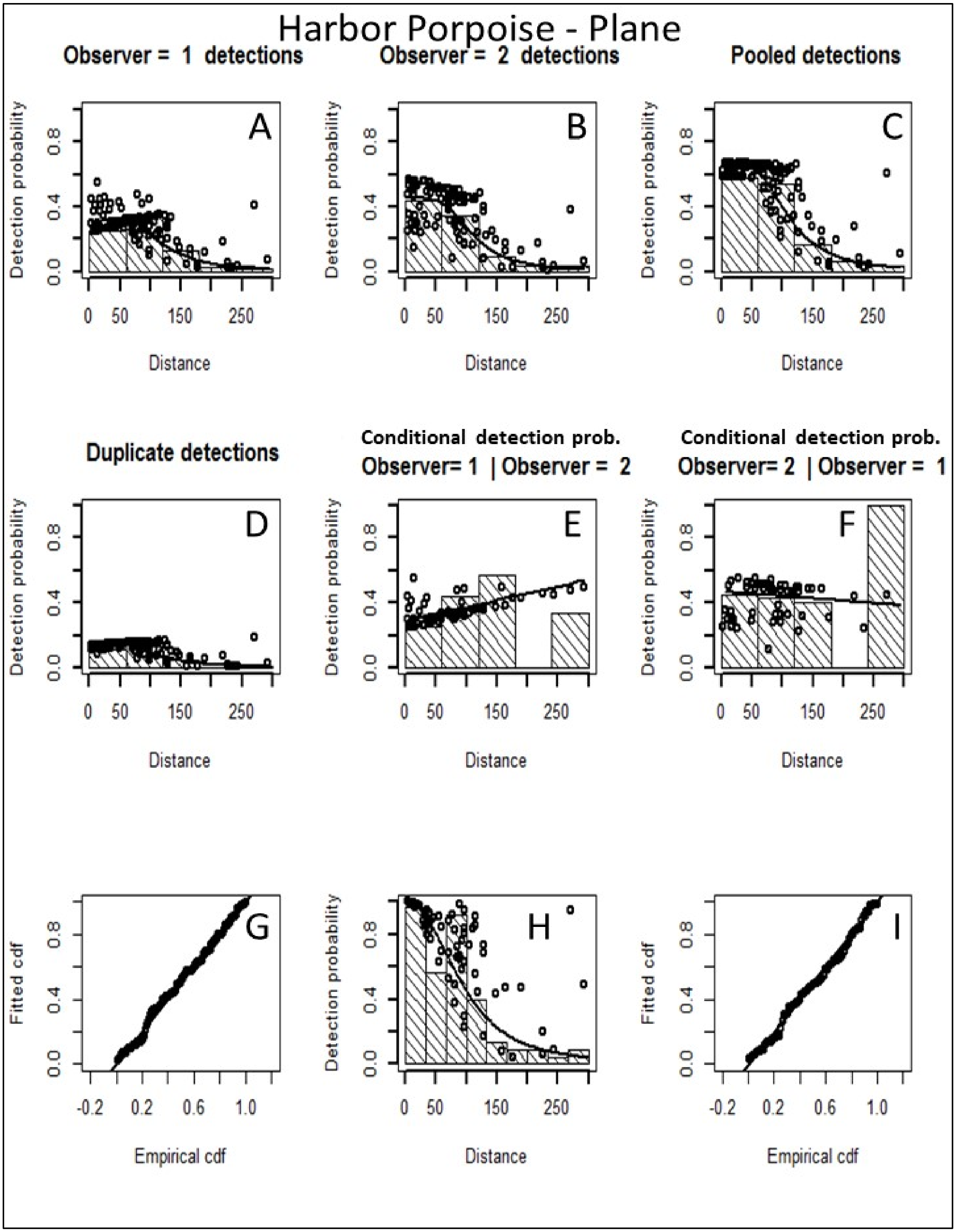

Figure A1- 1. Mark recapture and multiple distance sampling diagnostic plots for aerial data from harbor porpoises (*Phocoena phocoena*).

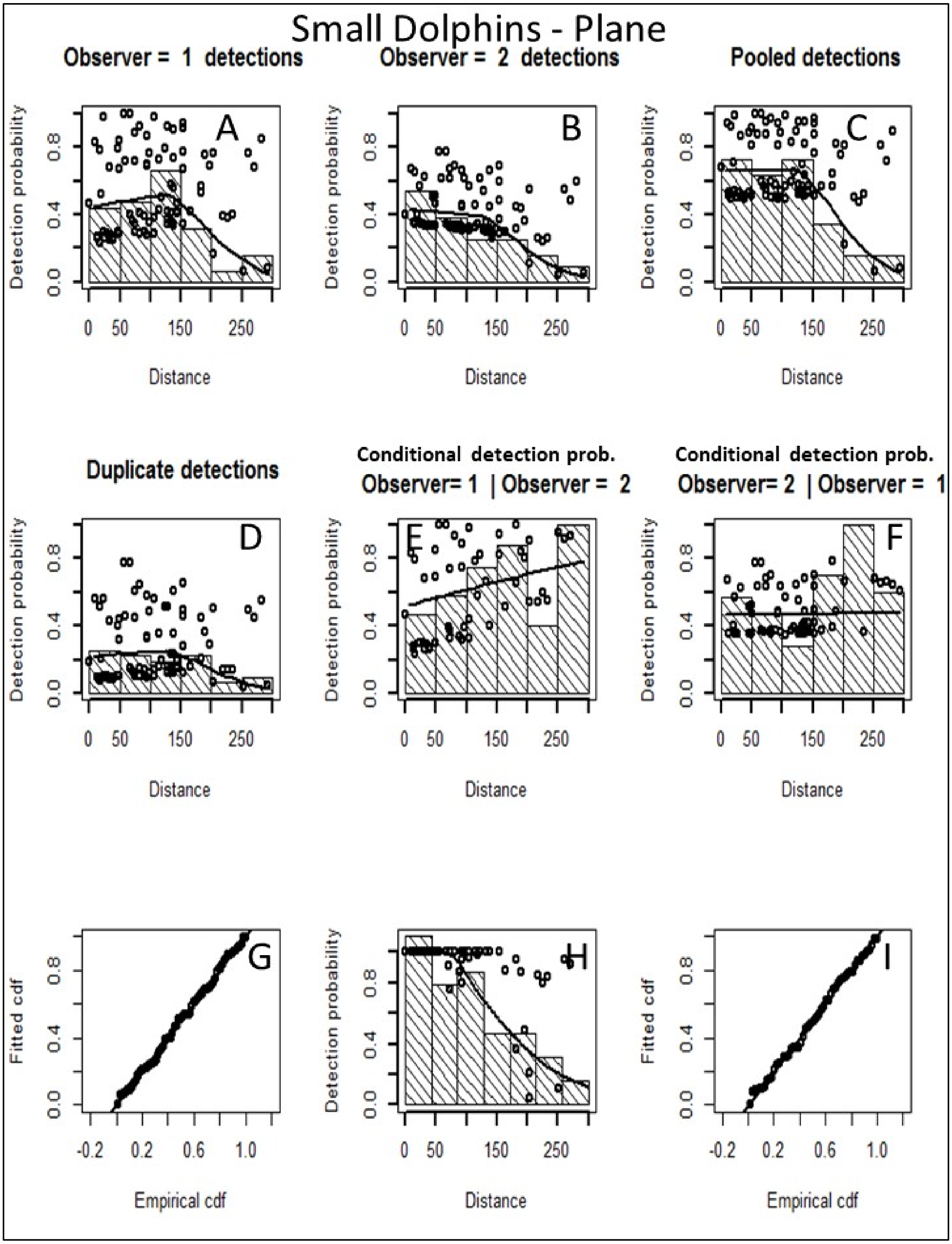

Figure A1- 2. Mark recapture and multiple covariate distance sampling diagnostic plots for aerial data from small dolphins (Atlantic white-sided [*Lagenorhynchus acutus*], common [*Delphinus delphis*], and common/white-sided dolphins).

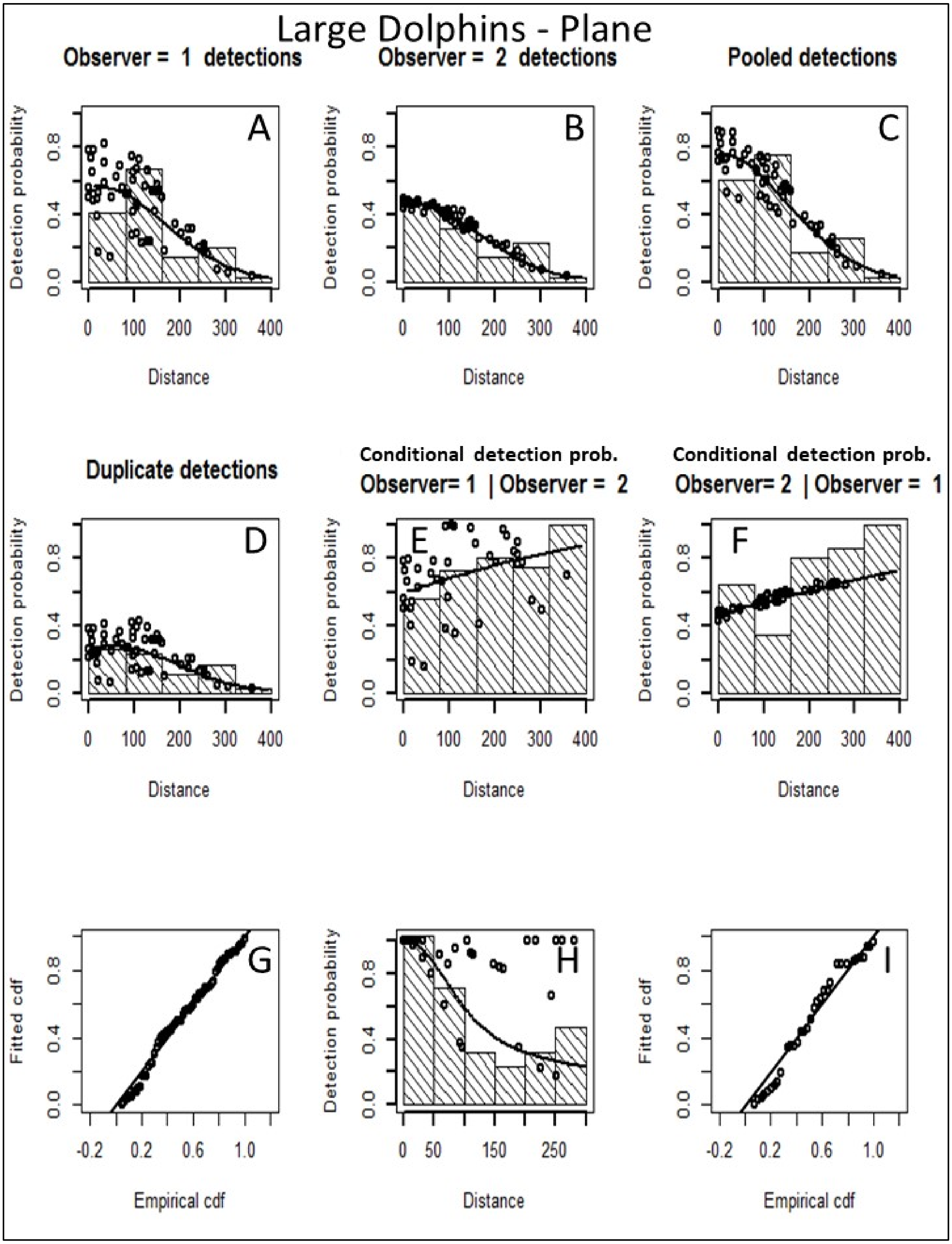

Figure A1- 3. Mark recapture and multiple covariate distance sampling diagnostic plots for aerial data from large dolphins (bottlenose dolphins [*Tursiops truncatus*], Risso's dolphins [*Grampus griseus*], and pilot whales [Globicephala spp.]).

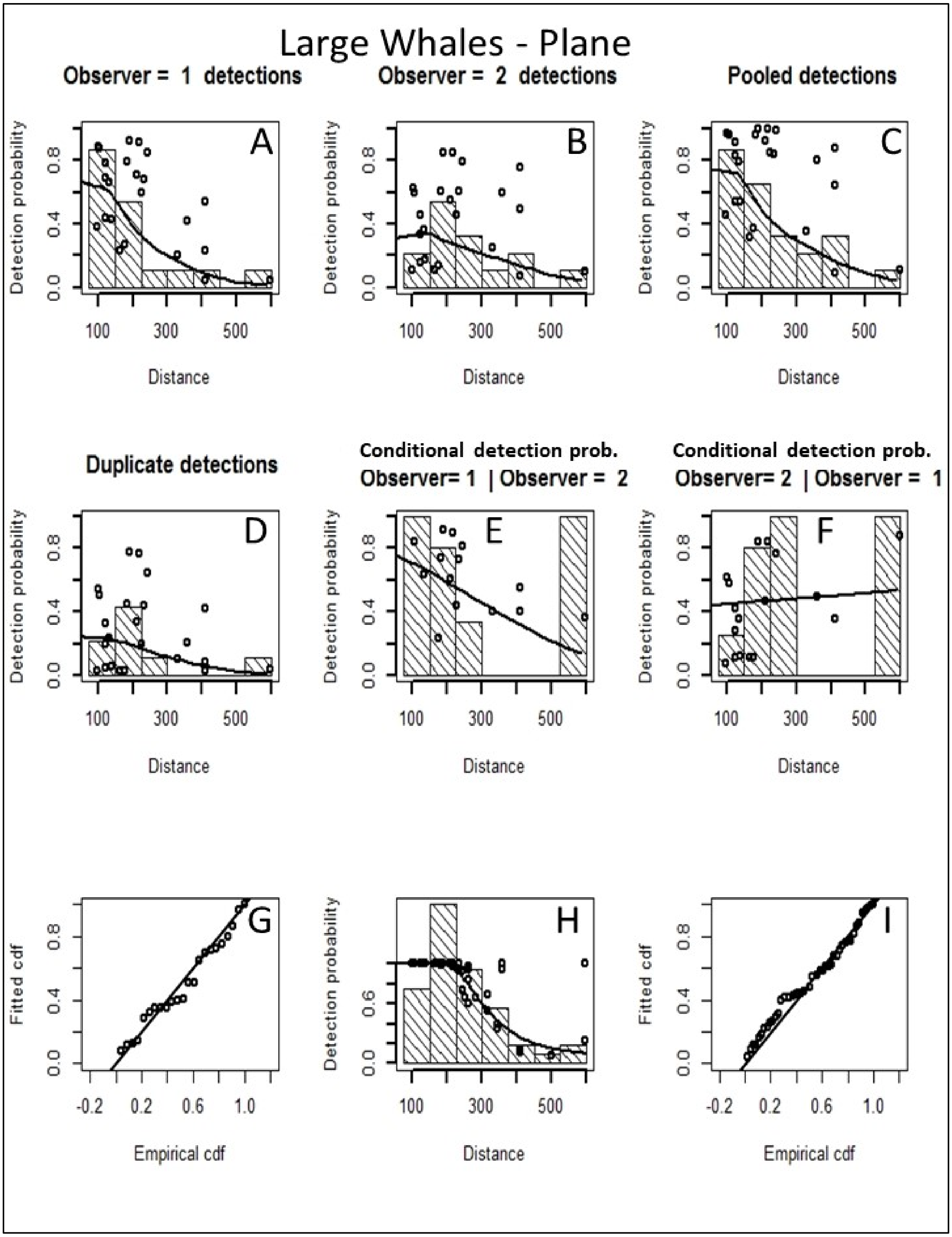

Figure A1- 4. Mark recapture and multiple covariate distance sampling diagnostic plots for aerial data from large whales (fin whales [*Balaenoptera physalus*], fin whales/sei whales [*Balaenoptera borealis*], humpback whales [*Megaptera novaeangliae*], and minke whales [*B. acutorostrata*]).

APPENDIX B. DIAGNOSTIC PLOTS FOR EACH SPECIES GROUPING FOR THE SHIPBOARD SURVEY

For each species grouping, the top team is designated as "Observer 1" and the lower team is "Observer 2" in the diagnostic plots that include the following:

A. A scaled histogram of upper team's detections; a line that is the average fitted distance sampling (DS) model scaled from the mark-recapture (MR) estimated g(0); and the points that are the estimated detection probability, given the covariate values and distance of each observation.
B. A scaled histogram of lower team's detections; a line that is the average fitted DS model scaled from the MR estimated g(0); and the points that are the estimated detection probability, given the covariate values and distance of each observation.
C. A scaled histogram of the pooled upper and lower teams' detections; a line that is the average fitted DS model scaled from the MR estimated g(0); and the points that are the estimated detection probability, given the covariate values and distance of each observation.
D. A scaled histogram of the duplicate detections; a line that is the average fitted DS model scaled from the MR estimated g(0); and the points that are the estimated detection probability, given the covariate values and distance of each observation.
E. The conditional MR detection probability (prob.) function for the upper team given detection by the lower team; a histogram of the proportion of sightings seen by the upper team given they were seen by the lower team; the fitted MR model averaged over covariate values; and points for each estimated detection probability for each observation.
F. The conditional MR detection probability (prob.) function for the lower team given detection by the upper team; a histogram of the proportion of sightings seen by the lower team given they were seen by the upper team; the fitted MR model averaged over covariate values; and points for each estimated detection probability for each observation.
G. A quantile-quantile (Q-Q) plot showing the goodness of fit of the fitted versus empirical cumulative distribution function (cdf) of the independent observer MRDS model.

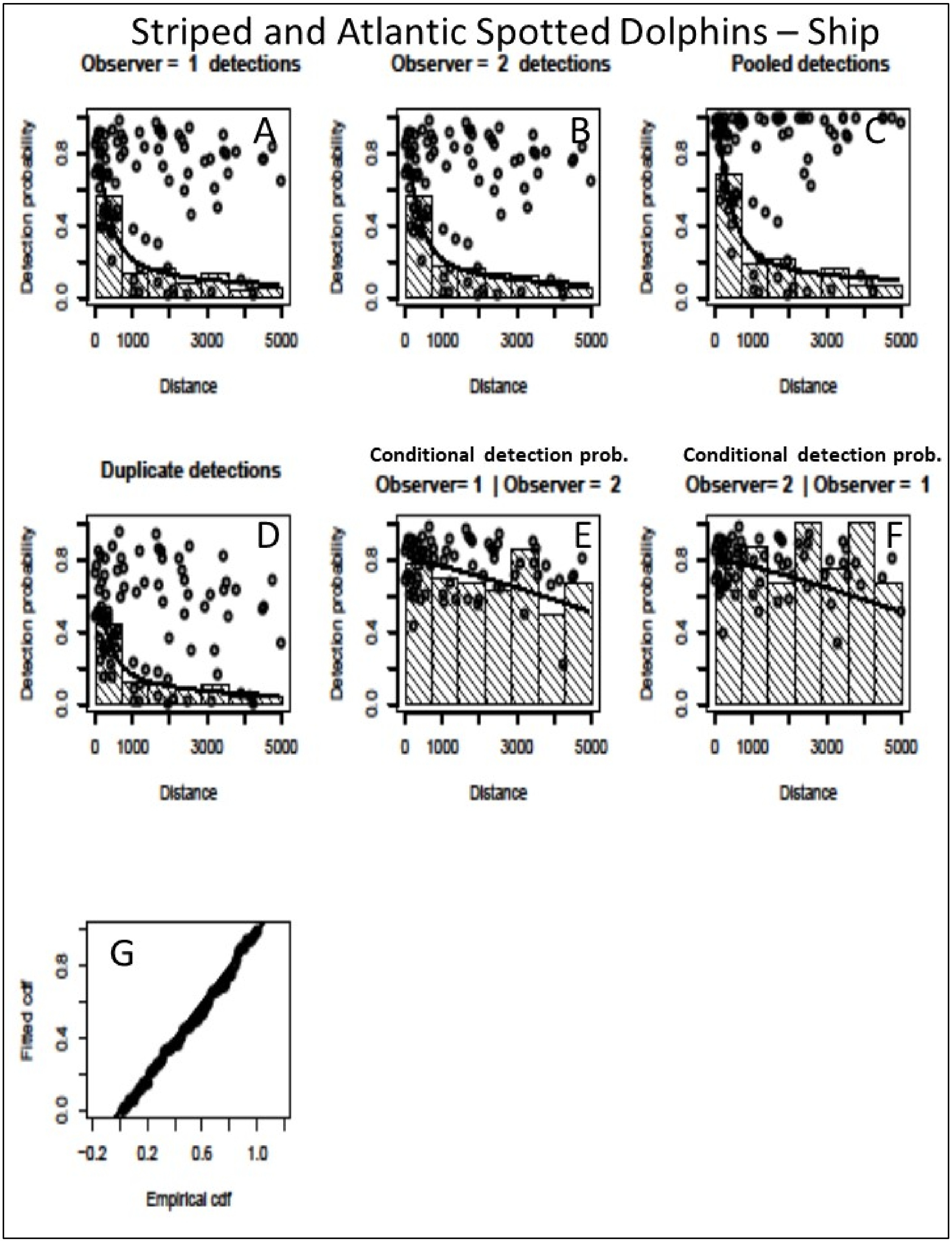

Figure A2- 1. Mark recapture distance sampling diagnostic plots for shipboard data from striped dolphins (*Stenella coeruleoalba*) and Atlantic spotted dolphins (*Stenella attenuata*).

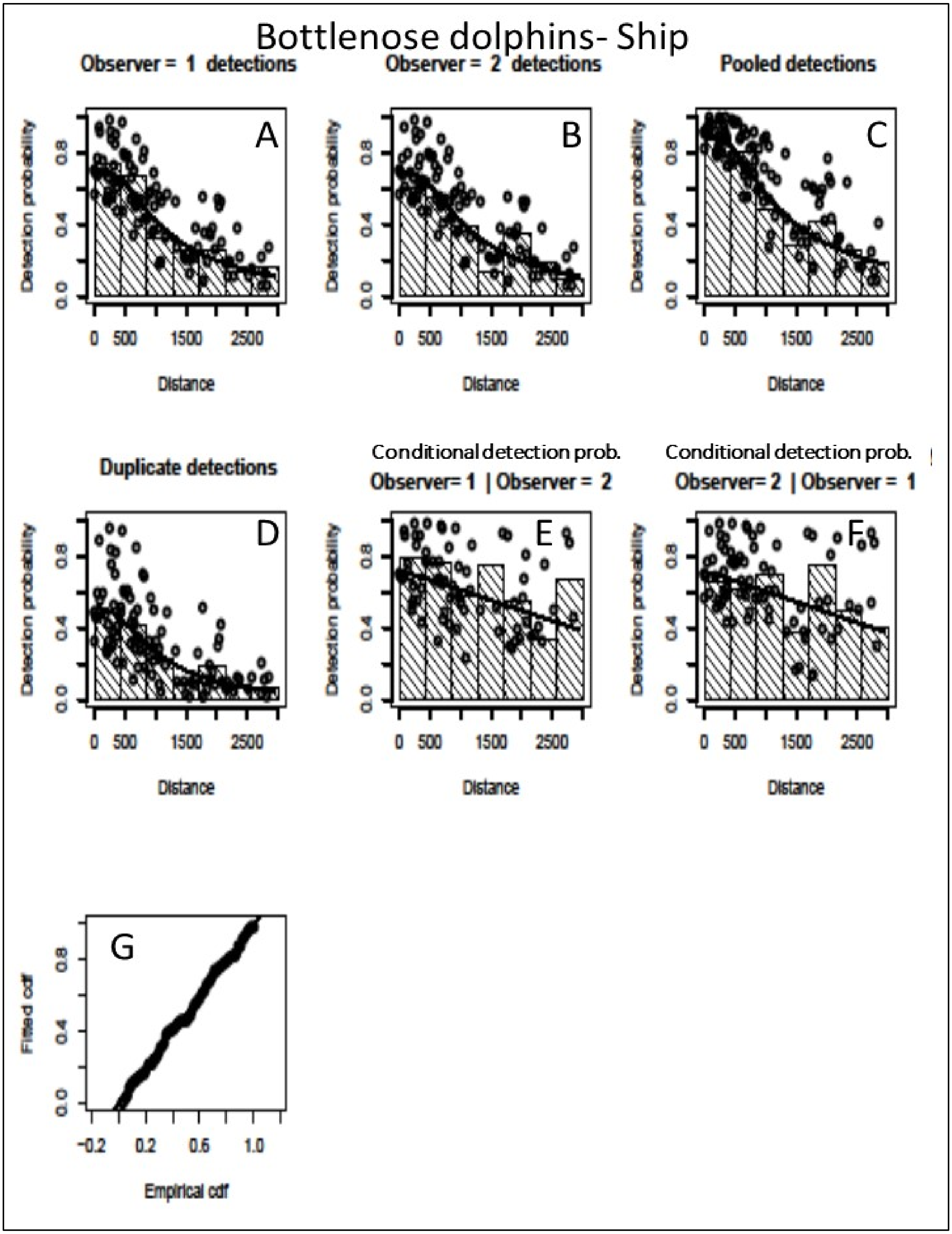

Figure A2- 2. Mark recapture distance sampling diagnostic plots for shipboard data from bottlenose dolphins (*Tursiops truncatus*).

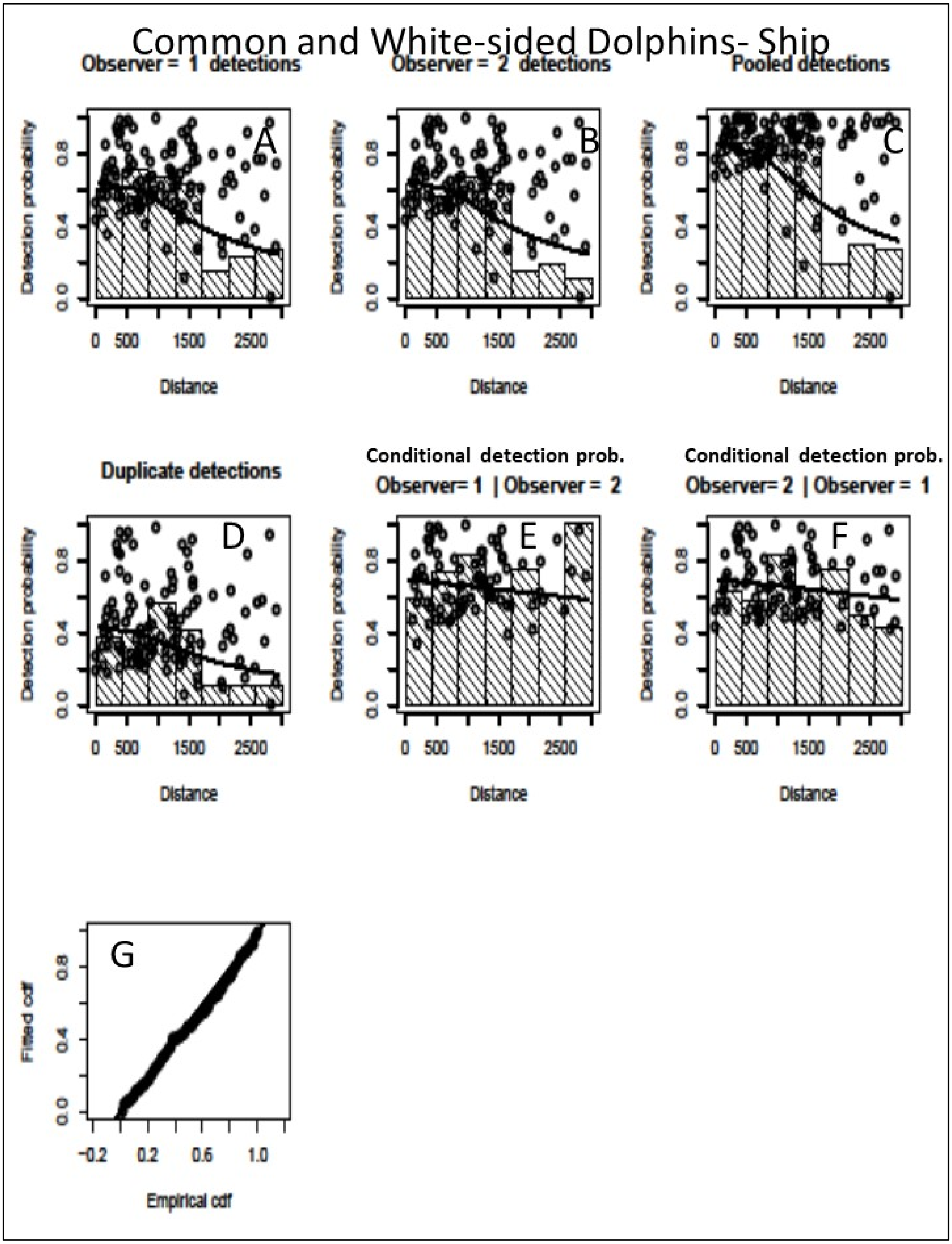

Figure A2- 3. Mark recapture distance sampling diagnostic plots for shipboard data from common (*Delphinus delphis*) and Atlantic white-sided dolphins (*Lagenorhynchus acutus*).

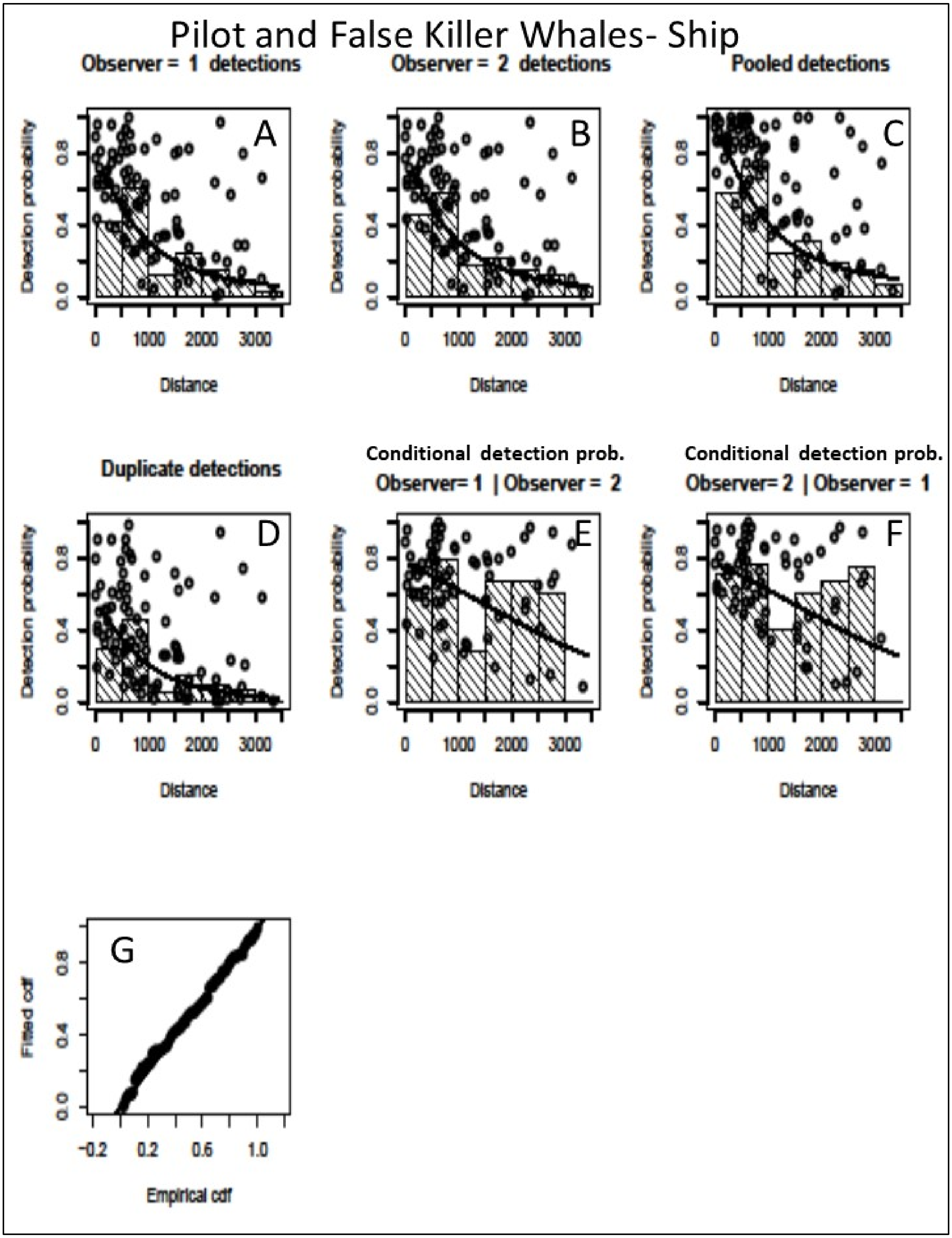

Figure A2- 4. Mark recapture distance sampling diagnostic plots for shipboard data from pilot whales (*Globicephala spp.*) and false killer whales (*Pseudorca crassidens*).

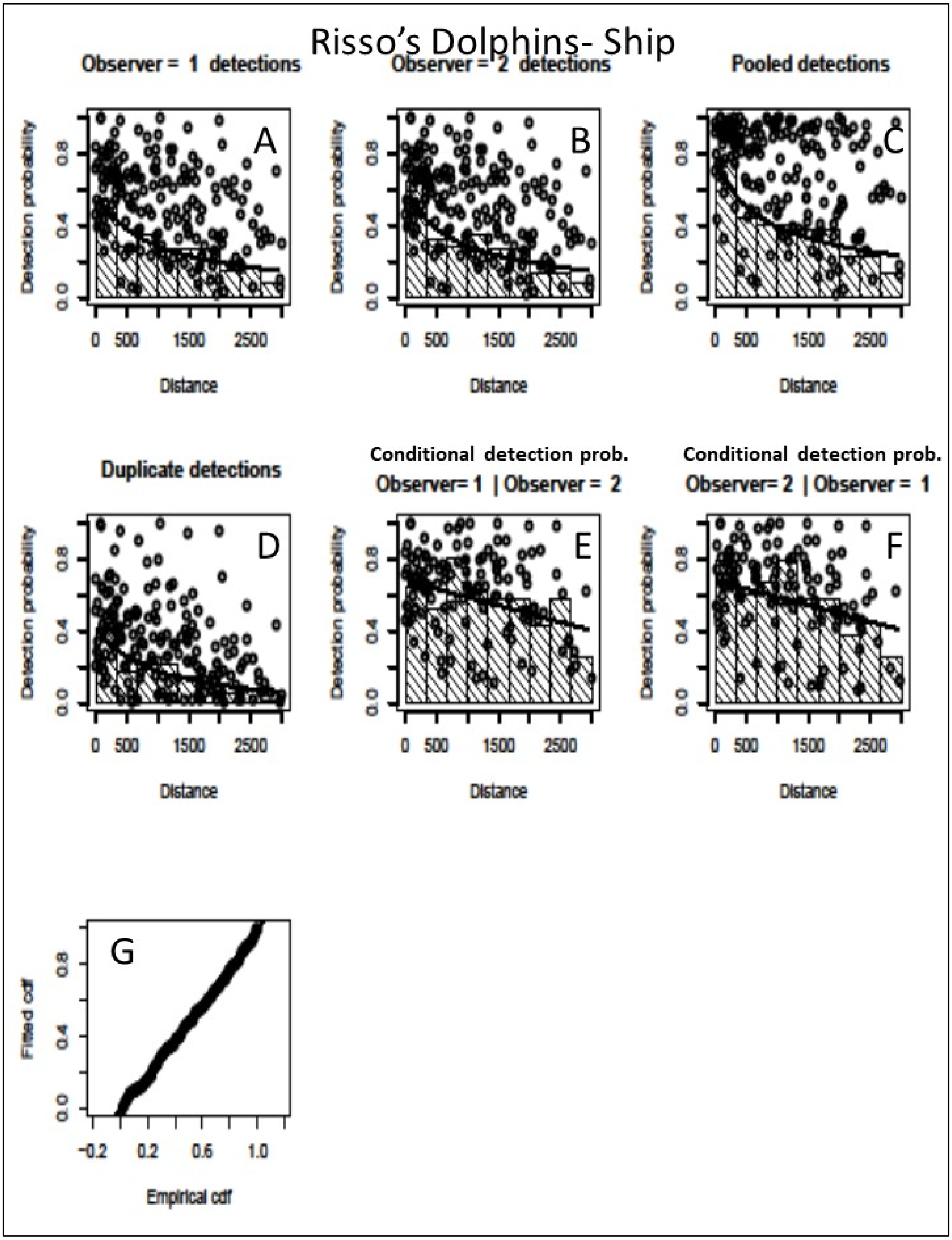

Figure A2- 5. Mark recapture distance sampling diagnostic plots for shipboard data from Risso's dolphins (*Grampus griseus*).

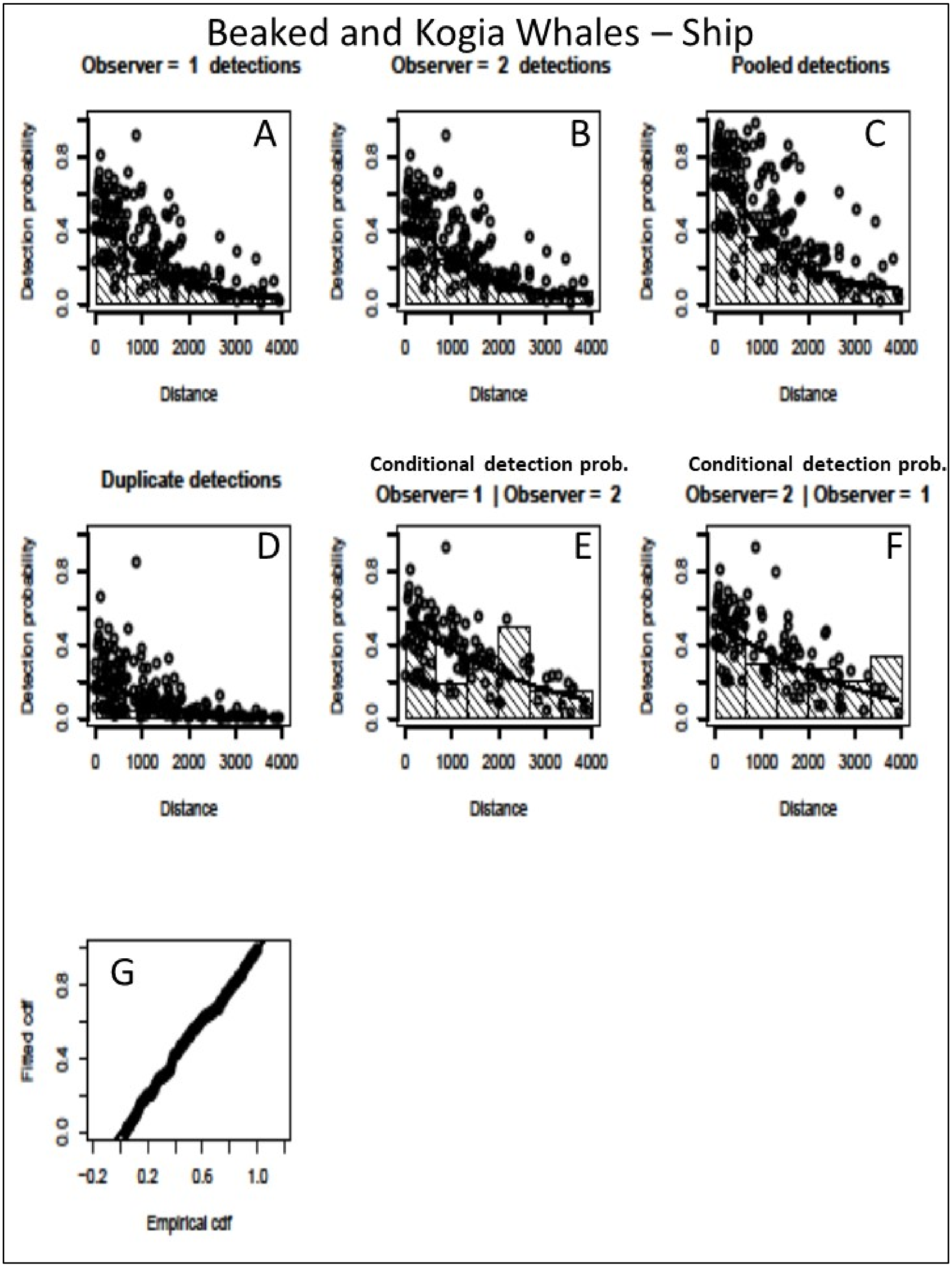

Figure A2- 6. Mark recapture distance sampling diagnostic plots for shipboard data from beaked whales and *Kogia spp*.

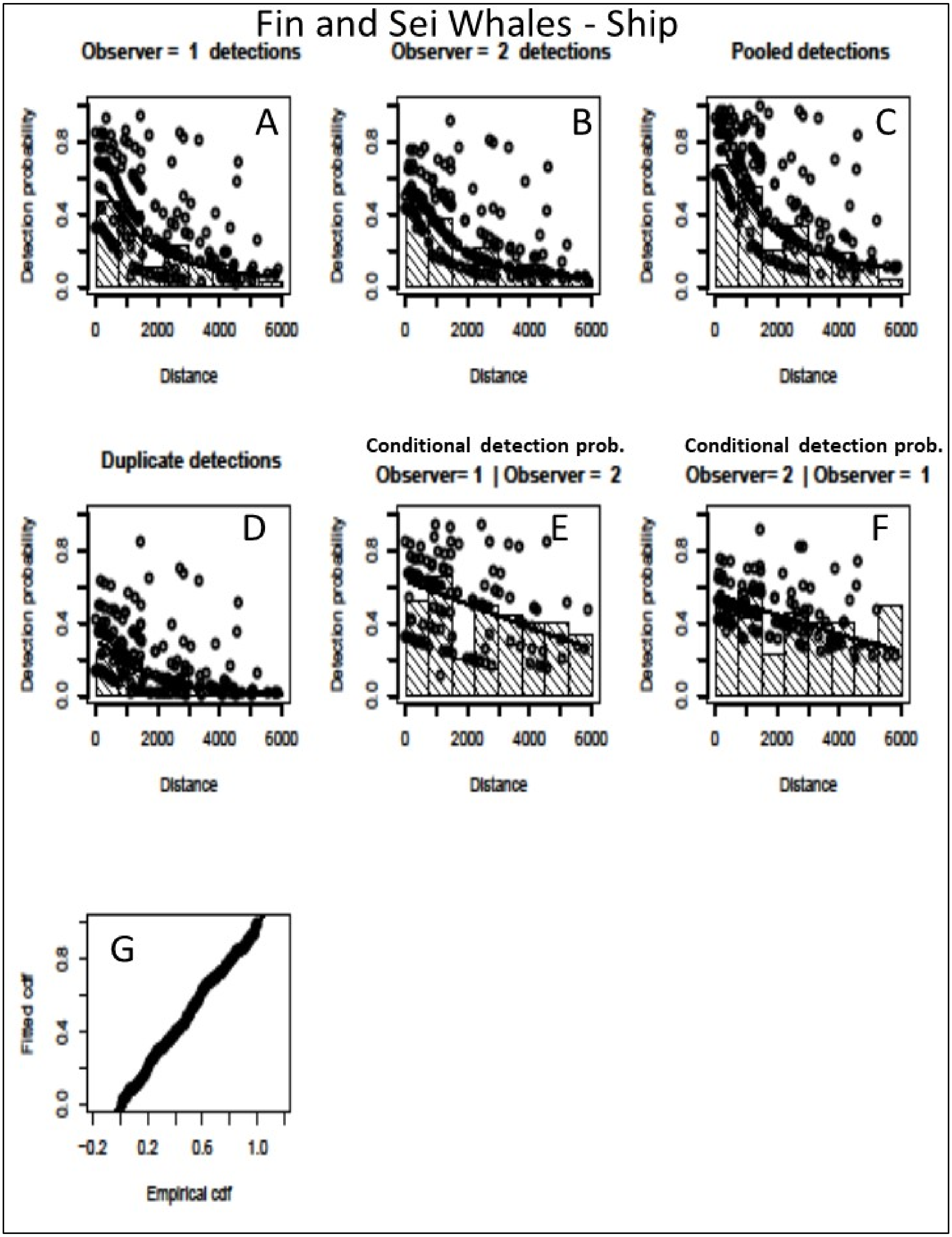

Figure A2- 7. Mark recapture distance sampling diagnostic plots for shipboard data from fin whales (*Balaenoptera physalus*), sei whales (*Balaenoptera borealis*), and fin/sei whales.

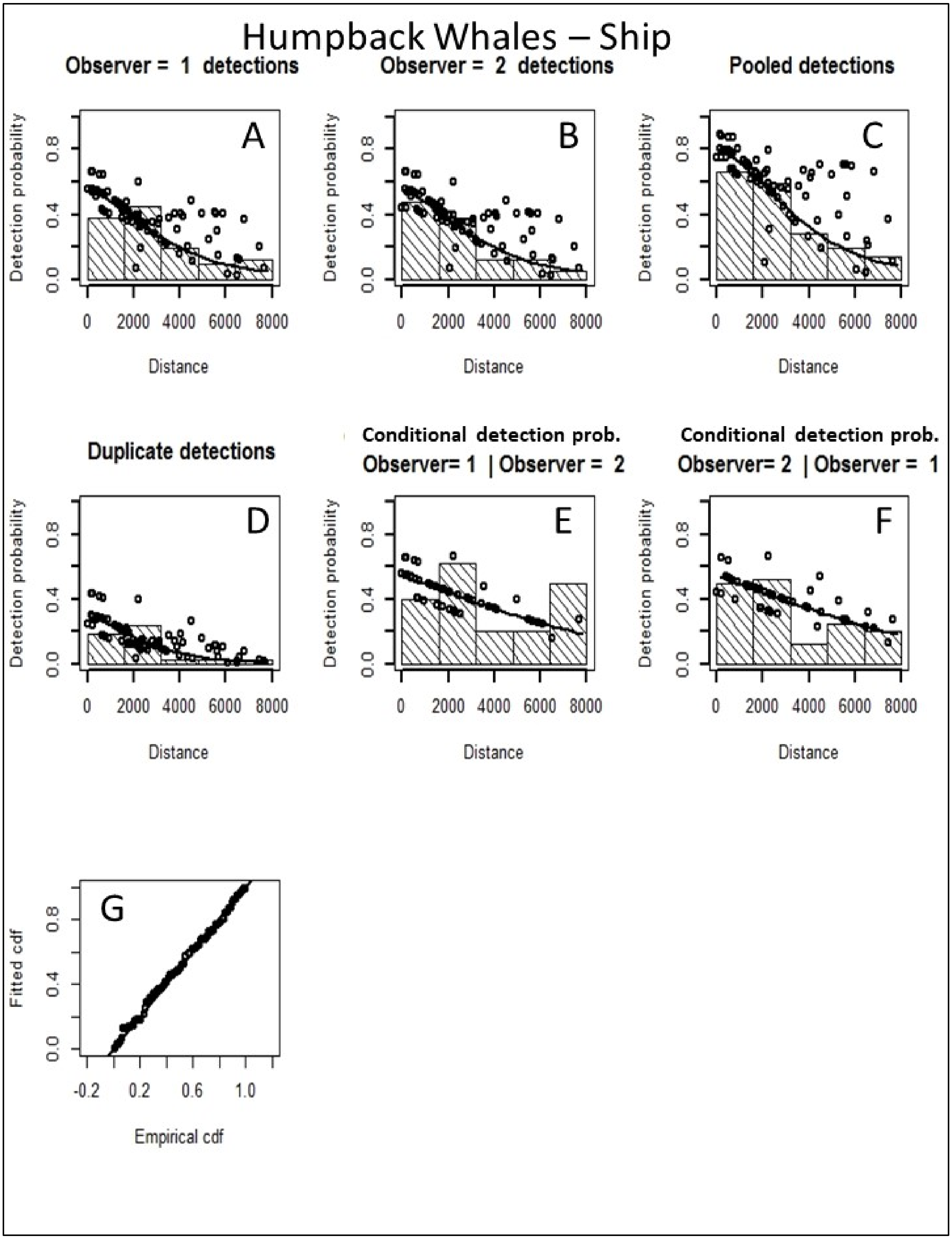

Figure A2- 8. Mark recapture distance sampling diagnostic plots for shipboard data from humpback whales (*Megaptera novaeangliae*).

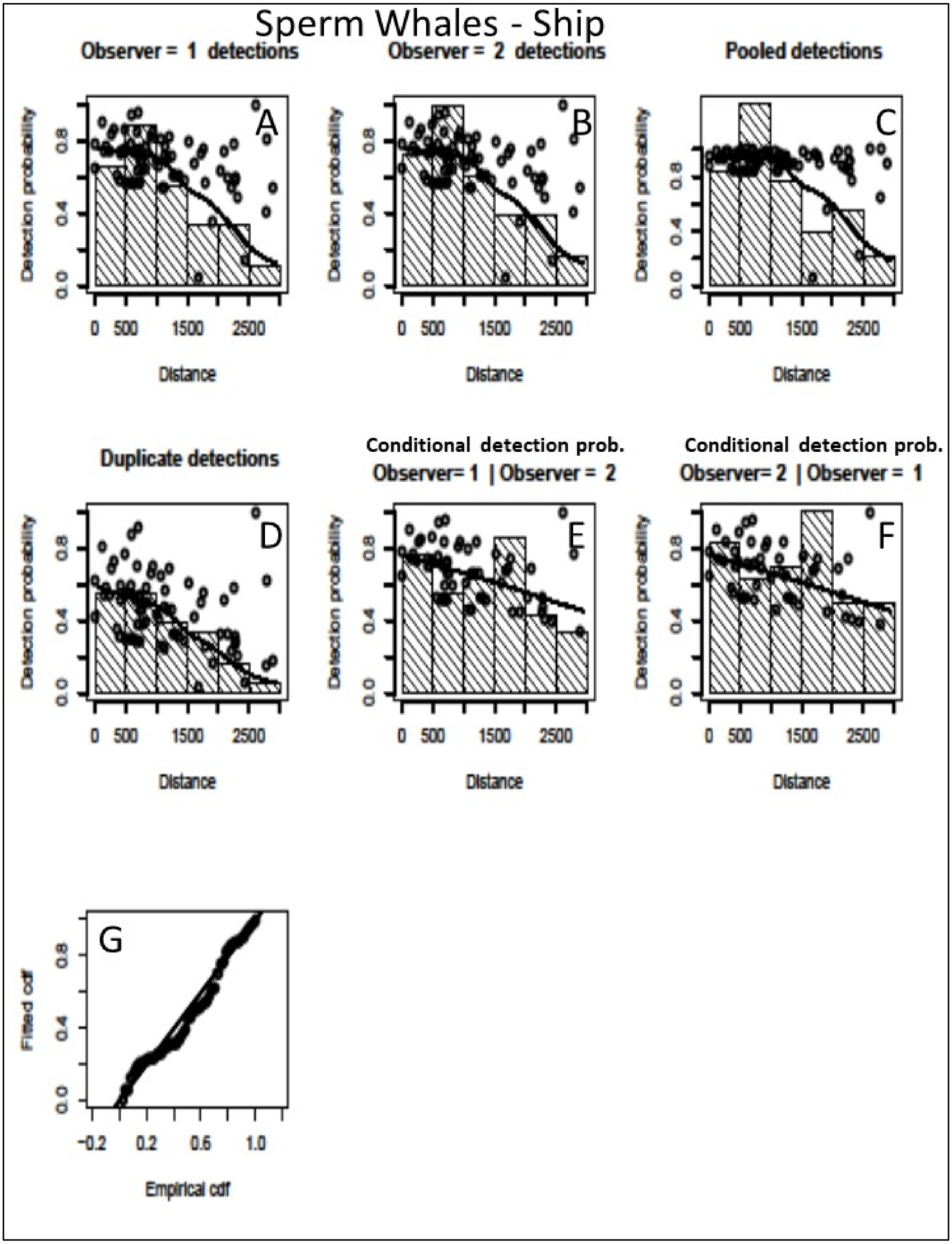

Figure A2- 9. Mark recapture distance sampling diagnostic plots for shipboard data from sperm whales (*Physeter macrocephalus*).

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